U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-266 598

The Swirl Concentrator for Erosion Runoff Treatment

American Public Works Association, Chicago, Ill

Prepared for

Municipal Environmental Research Lab, Cincinnati, Ohio Wastewater Research Div

Dec 76

PB 266 598

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-76-271

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
THE SWIRL CONCENTRATOR FOR EROSION RUNOFF TREATMENT

5. REPORT DATE
December 1976 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Richard H. Sullivan, Morris M. Cohn, James E. Ure, F. E. Parkinson, and Paul E. Zielinski

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
American Public Works Association
1313 East 60th Street
Chicago, Illinois 60637

10. PROGRAM ELEMENT NO.
1BC611

11. CONTRACT/GRANT NO.
68-03-0272

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
FINAL

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Supplement to "The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility," EPA-R2-72-008, September 1972 (NTIS PB-214 687). USEPA Project Officer: Richard Field, Telephone: 201-548-3347.

16. ABSTRACT

A device for the partial removal of erosion products in stormwater runoff has been developed. The swirl concentrator as an erosion control device has been designed to concentrate the heavier soils from large flows. The concentrated underflow of up to 14 percent of the flow can be directed to a forebay or settling basin.

The device is circular and for small watersheds a simple stock watering tank could be used with only minor modifications.

The design of the swirl concentrator as an erosion control device is based upon a hydraulic model study and research previously sponsored by the City of Lancaster, Pennsylvania and the U.S. Environmental Protection Agency into the mechanics of secondary motion flow-fields as developed in the swirl concentrator.

This report is submitted by the American Public Works Association in partial fulfillment of the contract 68-03-0272 between USEPA and APWA Research Foundation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Overflows Design Flow rate Swirling--separation Waste treatment *Erosion control Soil erosion	*Solids separation *Swirl concentrator Overflow quantity Overflow quality Stormwater runoff	13b

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS (This Report)
Unclassified

20. SECURITY CLASS (This page)
Unclassified

21. NO. OF PAGES
84

22. PRICE
PC:A05/MF:A01

EPA Form 2220-1 (9-73)

☆U.S. GOVERNMENT PRINTING OFFICE: 1977—757-056/5505

EPA-600/2-76-271
December 1976

THE SWIRL CONCENTRATOR FOR EROSION RUNOFF TREATMENT

By
Richard H. Sullivan, American Public Works Association
Morris M. Cohn, Consultant
James E. Ure, Alexander Potter Associates
F. E. Parkinson, LaSalle Hydraulic Laboratory, Ltd.
Paul E. Zielinski, Clemson University

Contract Number 68-03-0272

Project Officer

Richard Field
Storm and Combined Sewer Section
Wastewater Research Division
Municipal Environmental Research Laboratory (Cincinnati)
Edison, New Jersey 08817

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S.ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

The Municipal Environmental Research Laboratory – Cincinnati, has reviewed this report and approved its publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

As part of these activities, the study described here investigated the applicability of a swirl concentrator chamber to perform the function of concentrating erosion products from stormwater runoff.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A device for the partial removal of erosion products in stormwater runoff has been developed. The swirl concentrator as an erosion control device has been designed to concentrate the heavier soils from large flows. The concentrated underflow of up to 14 percent of the flow can be directed to a forebay or settling basin.

The device is circular and for small watersheds a simple stock watering tank could be used with only minor modifications.

The design of the swirl concentrator as an erosion control device is based upon a hydraulic model study and research previously sponsored by the City of Lancaster, Pennsylvania and the U.S. Environmental Protection Agency into the mechanics of secondary motion flow-fields as developed in the swirl concentrator.

This report is submitted by the American Public Works Association in partial fulfillment of the contract 68-03-0272 between USEPA and APWA Research Foundation.

CONTENTS

Page No.
Chapter I Overview, Conclusions and Recommendations 1
Chapter II The Study 6
Chapter III Design Factors for Swirl Erosion Runoff Treatment Prototypes 13
Chapter IV Glossary of Pertinent Terms 31
Chapter V Appendix – LaSalle Hydraulic Laboratory Report 32

TABLES

1 Sieve Analysis 24
2 Swirl Efficiency Analysis 26
3 Modifications Tested in Model and Results 45
4 Comparable Recovery Rates for Sloping and Horizontal Chamber Floors 62
5 Percent Suggested Recovery in Model 69

FIGURES

1 Schematic View, Swirl Concentrator as an Erosion Runoff Treatment Facility 3
2 Flow Diagram 4
3 Model Layout 9
4 Original Layout for Test No. 1 10
  a Plan and Elevation 10
  b Photos, Original Layout and Original Layout with Inlet Baffle 11
5 Prototype Particle Sizes Represented by Gilsonite – 1.06 14
6 Recovery Rates on Model as Function of Particle Settling Velocity and Discharge with 5 Percent Draw-off 15
7 Recovery Rates on Model as Function of Particle Settling Velocity and Discharge with 10 Percent Draw-off 16
8 Recovery Rates on Model as Function of Particle Settling Velocity and Discharge with 14 Percent Draw-off 17
9 Predicted Prototype Recovery Rates with 5 Percent Draw-off 18
10 Predicted Prototype Recovery Rates with 10 Percent Draw-off 19
11 Predicted Prototype Recovery Rates with 14 Percent Draw-off 20
12 General Design Dimensions, Scale – 1:4 21
13 Prototype Particle Sizes Represented by Petrothene – SG 1.01 25
14 Standard Stock Watering Tank 29
15 Gradation Curve for Gilsonite Used in Model 34

FIGURES (Continued)

Page No.

16 Prototype Settling Velocities Simulated by Gilsonite – SG 1.06 35
17 Gradation Curve for Petrothene Used in Model 37
18 Prototype Settling Velocities Simulated by Petrothene – SG 1.01 38
19 Prototype Particle Sizes Represented by Petrothene – SG 1.01 39
20 Range of Prototype Grit Particle Sizes (SG 2.65) Simulated, Respectively, by Gilsonite, Petrothene and Petrothene Dust 40
21 Settling Velocity Distributions for Petrothene Dust and Stormwater Runoff 41
22 Settling Velocity Distributions for Shredded Petrothene X and Stormwater Runoff 42
23 Settling Velocity Distribution for Gilsonite and Stormwater Runoff 43
24 Model Layout for Tests 2 to 13, Modification 1 47
  a Plan and Elevation 47
  b Photos, Uneven Flow Spoilers Stuck on the 50.8 cm (20 in.) Weir Disk and Modification 1, Tested with a 3 l/sec (0.8 gal/sec) Discharge 48
25 Photos, Deposit of Petrothene Found After 3 l/sec (0.8 gal/sec) Test 49
26 Influence of Inlet Deflector on Recovery Rate 0.50 m (20 in.) ϕ Weir Disk 5 Percent Draw-off, Modification 11 50
27 Model Layout for Tests 14 to 16, Modification 2 51
28 Model Layout for Tests 17 to 19, Modification 3 53
29 Photos, Inlet Baffle, Modification 3 54
30 Model Layout for Tests 20 to 22, Modification 4 55
31 Photos, Details, Modification 4 56
32 Model Layout for Tests 23 to 31, Modifications 5, 6, and 7 57
33 Model Layout for Tests 32 to 35, Modification 8 58
34 Model Layout for Tests 36 to 38, Modification 9 59
35 Photos, Details, Modification 7 60
36 Influence of Weir – Chamber Diameter Ratio 61
37 Model Layout for Tests 39 to 41, Modification 10 63
38 Model Layout for Tests 42 to 59 and 69 to 107, Modification 11 64
39 Influence of Chamber Floor Slope 65
40 Influence of Continuous Underflow Draw-off, Modification 11 66
41 Model Layout for Tests 60 to 68, Modification 12 67
42 Influence of Inlet Size 68
43 Suggested Recovery Curves for Gilsonite and Petrothene in Model with 5 Percent Draw-off 70
44 Suggested Recover Curves for Gilsonite and Petrothene in Model with 10 Percent Draw-off 71
45 Suggested Recovery Curves for Gilsonite and Petrothene in Model with 14 Percent Draw-off 72
46 Retention Times for Prototype 73

ACKNOWLEDGEMENTS

The American Public Works Association is deeply indebted to the following persons and their organizations for the services they have rendered to the APWA Research Foundation in carrying out this study for the U. S. Environmental Protection Agency.

PROJECT DIRECTOR

Richard H. Sullivan

CONSULTANTS

Dr. Morris M. Cohn, P.E., Consulting Engineer
Paul B. Zielinski, P.E.

ALEXANDER POTTER ASSOCIATES, CONSULTING ENGINEERS

Morris H. Klegerman, P.E.
James E. Ure, P.E.

LA SALLE HYDRAULIC LABORATORY, LTD.

F. E. Parkinson
George Galina

U. S. ENVIRONMENTAL PROTECTION AGENCY

Richard Field, P.E., Project Officer, Chief, Storm & Combined Sewer Section (Edison, New Jersey)

AMERICAN PUBLIC WORKS ASSOCIATION
Board of Directors

Ray W. Burgess, President
John J. Roark, Vice President
Herbert A. Goetsch, Immediate Past President
Robert D. Bugher, Executive Director

Joseph F. Casazza
John T. Carroll
William B. Drake
Lambert C. Mims
James J. McDonough
Robert D. Obering
Robert C. Esterbrooks
James E. McCarty
Kenneth A. Meng
Frank R. Bowerman
N. W. Diakiw
Rear Admiral A. R. Marschall

APWA RESEARCH FOUNDATION
Board of Trustees

Samuel S. Baxter, Chairman
Ross L. Clark, Vice Chairman
Robert D. Bugher, Secretary-Treasurer
Richard H. Sullivan, General Manager

John F. Collins
Jean L. DeSpain
William B. Drake
Richard Fenton
William C. Gribble, Jr.
Erwin F. Hensch
John A. Lambie
Harold L. Michael

CHAPTER I
OVERVIEW, CONCLUSIONS AND RECOMMENDATIONS

Overview of the Study Project

The discharge of erosion runoff solids and other debris into receiving waters represents a source of water pollution of significant proportion. Numerous points of construction and reconstruction which involve disturbance of the native soil and earth-moving operations make control of erosion and treatment of such runoff stormwaters an important factor in protecting the nation's water resources, eliminating damage to reservoirs and other water areas, and preventing impairment of the natural beauty of the land.

The recent level of such construction as subdivision housing and highway projects may continue and increase in the future, adding further reason for invoking the principle of control and treatment of erosion wastewaters.

Study of the application of the swirl solids-liquid separator for the removal of suspended solids contained in stormwater erosion flows is a natural consequence of the proven ability of such secondary-flow patterns in similar hydraulic devices to remove substantial amounts of solids from combined sewer overflows during wet-weather flow incidents; to classify and separate grit from sanitary and combined sewer wastewaters; and to achieve clarification, or primary treatment, of wastewaters in treatment plants. These solids-removal uses of swirl chambers have been demonstrated in a series of sequential hydraulic and mathematical model studies carried out as parts of previous investigations by the American Public Works Association (APWA) Research Foundation for, and on behalf of, the U.S.Environmental Protection Agency (USEPA) and other involved entities. These reports include:

- The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility, EPA-R2-72-008
- Relationship Between Diameter and Height for the Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator, EPA-670/2-74-039
- The Swirl Concentrator as a Grit Separator Device, EPA-670/2-74-026
- Helical Bend Combined Sewer Overflow Regulator, EPA-600/2-75-062

These studies were, in particular, directed toward solution of point pollution problems.

In addition, studies are being conducted by Onondaga County, Syracuse, New York, USEPA Grant No. S-802400 – swirl overflow regulator, full-scale prototype; Metropolitan Toronto, Ontario, USEPA Grant No. S-803157; – swirl primary separator, pilot; Metropolitan Sewer District No. 1, Denver, Colorado, USEPA Grant No. S-803157 – swirl degritter, pilot; Monroe County Pure Waters Agency, Rochester, New York, USEPA Grant No. Y-005141, swirl primary separator and degritter, pilots; The University of Wisconsin, Milwaukee, project, grit and floatables; and Clemson University, South Carolina, project, aquiculture wastes.

The study of the applicability and capability of modified swirl concentrator chamber facilities to serve a related solids-removal function for nonpoint pollution control resulted from the successful demonstrations of these direct uses in sewer systems. The utilization of the swirl secondary-flow pattern to alleviate a nonpoint drainage pollution problem is, therefore, a "fourth-generation" approach to a related resources protection need. The simplicity of the model swirl device studied, and of the proposed prototype units for actual field installations, should offer a workable opportunity to apply this hydraulic principle for the correction of a major source of water and land resources despoilation.

The final result of the model erosion treatment studies undertaken by the APWA Research Foundation at the LaSalle Hydraulic Laboratory at LaSalle, Quebec, has been to provide the basis of an economical, effective swirl device which can utilize a relatively inexpensive standard cattle watering tank, properly modified, fitted, and equipped, for the purpose of removing adequate amounts of earthen material contained in nonpoint-stormwater erosion runoff flows. The use of a conventional, purchasable basin or tank which can be installed at a point to intercept and treat erosion waters offers the added advantage that this unit can be removed with minimum effort and expense, transferred to another location and reinstalled to handle such flows at any other point of erosion. This flexibility makes the swirl device useful during construction work, and removable and reusable in connection with other similar projects. It, therefore, falls into the category of a construction "tool" which contractors or governmental or private field crews can use to meet temporary needs.

The development and demonstration of the performance of the model swirl erosion runoff treatment unit involved the use of a 0.9-m (3 ft) scaled laboratory hydraulic model made of Plexiglas® fitted with a pipe inlet, a 15.24-cm (6 in) control circular overflow pipe and spill weir for clarified storm erosion water, a foul sewer outlet, and other investigative internal appurtenances. Facilities were provided for the measured introduction of small particles of Petrothene® and Gilsonite® specific gravity 1.01 and 1.06 respectively, into the incoming water stream to simulate grit and other solids material in erosion runoff, and for collection and evaluation of solids discharged through the foul sewer outlet and contained in the clarified overflow.

A series of twelve modifications were made in the internal structure of the swirl model. A cycle of 62 exhaustive performance tests was carried in the swirl chamber, covering liquid flow and solids separation phenomena under these modifications. After investigation of all of the variations in the model, the studies were finalized in terms of the optimum configuration and ratio of sizes and locations of the variable components. Original studies of performance with a sloping bottom floor were discontinued and subsequent findings were based on a flat-floor configuration. This made it possible to translate design criteria in terms of use of standard cattle watering tanks as the "shell" of prototype swirl chambers for treating erosion storm flows.

The effect of continuous draw-off of collected grit material, via the swirl concentrator chamber foul sewer outlet, on solids recovery demonstrated the beneficial effects of such removal on entrained solids. The hydraulic studies served as the basis for the evolvement of suggested recovery rate or performance curves, influenced by foul material draw-off and particle settling velocities. General design dimensions were ascertained for actual prototype installations; designing engineers will be provided with the structural, and appurtenant design criteria and step-by-step instructions on how to utilize the study curves to determine and predict swirl removal performance levels.

Figure 1, Schematic View, Swirl Concentrator as an Erosion Runoff Treatment Facility, shows the essential features of the device.

The essential features, as indicated on Figure 1 include:

a) a round outer shell
b) a flat floor
c) an internally supported clear water overflow weir with a bottom discharge
d) a concentrate discharge take-off to a settling basin
e) a baffled inlet to insure the development of the swirl flow field
f) flow spoilers to improve the efficiency of the circular discharge weir.

Figure 2, Flow Diagram, indicates the basic assumptions concerning the use of the device. A permanent installation will require a flow-splitting diversion device, where multiple units are used, and bar screens to protect the units from coarse debris. A settling pond or other facility will be required to handle the 5 to 14 percent concentrated underflow from the swirl assembly. The clarified flow may be run into a detention pond or directly into receiving water, based upon the degree of protection against erosion solids required by receiving water quality standards.

Conclusions

The following conclusions can be drawn from the studies carried out at the LaSalle Hydraulic Laboratory, LaSalle, Quebec, on the applicability and capability of the swirl concentrator for the treatment of surface erosion runoff.

- A properly designed and proportioned swirl concentrator chamber can perform an

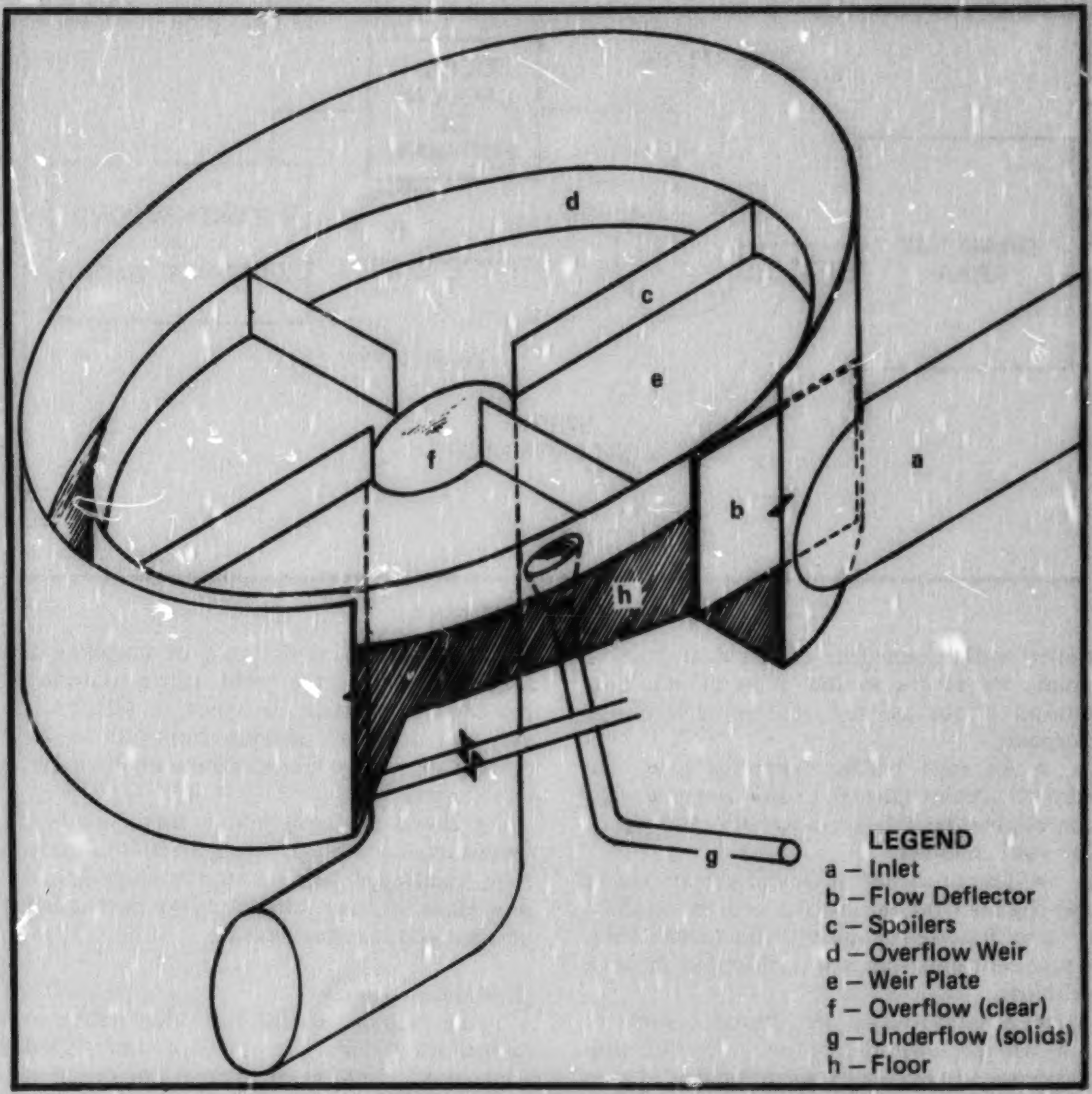

a
b
c
d
e
f
g
h
LEGEND
a – Inlet
b – Flow Deflector
c – Spoilers
d – Overflow Weir
e – Weir Plate
f – Overflow (clear)
g – Underflow (solids)
h – Floor

FIGURE 1 SCHEMATIC VIEW, SWIRL CONCENTRATOR AS AN EROSION RUNOFF TREATMENT FACILITY

effective job of removing erosion particles from stormwater runoff, and thereby markedly reduce the effects of soil erosion and the impact of such earth solids on contiguous land and surface waters which are the recipients of the erosion materials.

- Such a swirl device can be rapidly and economically installed at points of erosion runoff by use of a standard or conventional cattle watering tank having a 3.66-m (12 ft) diameter and a 0.9-m (3 ft) depth, fitted and equipped with a suitable inlet line, a circular overflow weir, a foul sewer outlet, and necessary interior appurtenances. Such a chamber could be readily disassembled, moved to another site, and reinstalled for the treatment of erosion runoff flows.

- The desilted, or clarified effluent could be discharged to drainage facilities and disposed of into receiving waters or other points of disposal or use. The collected matter could be discharged through the foul sewer

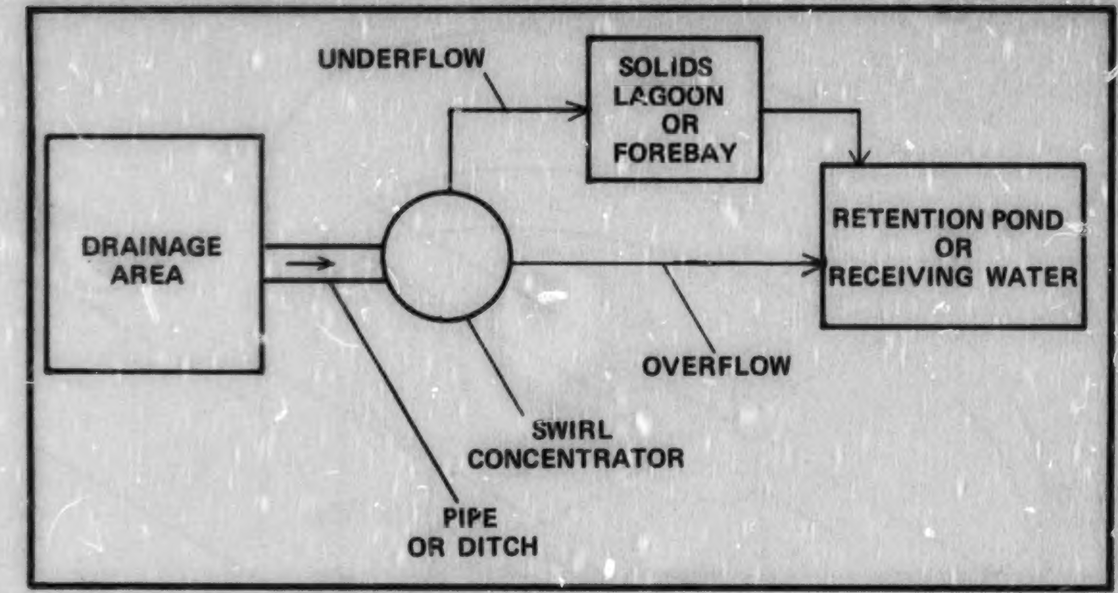


FIGURE 2 FLOW DIAGRAM

outlet and entrained or collected at suitable points for return to the point or points of erosion or for use for other predetermined purposes.

- An inlet baffle, extending from the inlet to a point tangent to the overflow weir, can double the solids removal effectiveness of the swirl chamber.
- The retention of floatable materials in the chamber, by means of a concentric skirt, is not feasible; however, floatables from nonpoint runoff are not anticipated to be a problem.
- A weir-to-chamber diameter ratio of 2:3 will produce the optimum clarification efficiency in the swirl clarification device.
- Continuous draw-off of the collected erosion material through the foul sewer opening in the bottom of the swirl chamber enhances the solids removal efficiency of the unit.
- An inlet pipe-to-chamber diameter ratio of 1:6 will produce effective grit solids removal efficiencies for low, intermediate, and high rates of erosion runoff discharges.
- Use of standard cattle watering tanks for the swirl chamber will be simplified if the chamber bottom is left flat, rather than being sloped to the point of foul sewer outlet. If higher degrees of erosion runoff clarification are desired, and if the cost of installing a sloping floor in the swirl cattle watering chamber is merited, increases in efficiency may be achieved, ranging from 10 to 25 percent for maximum and minimum discharge rates, respectively.
- Based on the hydraulic model studies, practicable prototype design criteria have been developed and a step-by-step design procedure utilizing rational design curves and detailed sketches has evolved.

Recommendations

The erosion of soil and other native or indigenous materials at points of unprotected land areas, such as at general construction sites, housing developments, and highway location and relocation projects, can be damaging to the nation's land and water resources. Various means should be instituted to prevent the washing or scouring of such materials and the disturbance of sites, and the damaging of environmental aesthetics. When erosion has occurred, or is occurring, it is beneficial to intercept the disturbed soil material and to make provision for its return to the eroded areas, or to make provision for its use for other purposes. Treatment of erosion runoff waters will prevent obvious and visible water pollution conditions and prevent heavy siltation of reservoirs, streams, and lake areas.

The ability of a simple swirl chamber constructed of a standard cattle watering tank to be moved and reinstalled at other sites – as demonstrated by hydraulic model studies carried out under this investigation project at the LaSalle Hydraulic Laboratory – should promote its utilization for erosion runoff treatment.

- It is recommended that erosion runoff treatment units of the swirl type be installed at a number of sites in accordance with prototype design recommendations. These prototype units should be placed under technical study to ascertain their solids removal efficiency under practical field conditions.
- Any modifications in basic design, or in the size and location of appurtenant parts of the swirl device, should be researched to compare findings with other installations in the first prototype group and to establish standards for future utilization of this simple treatment device.

CHAPTER II
THE STUDY

Because of the potential impact of erosion runoff on water quality and soil conservation and current concern over corrective actions that will prevent such conditions, APWA, under contract to the USEPA, has conducted a study of the applicability of the simple, economical swirl concentrator principle to the problem of removing erosion products from stormwater runoff.

The hydraulic model studies[1-4] were carried out at the LaSalle Hydraulic Laboratory, where all of the previous investigations of the swirl concentrator were performed for APWA-USEPA research projects. The research swirl facilities which were utilized in the previous studies of combined sewer overflow regulation and clarification,[1,2] removal of grit from wastewater flows,[3] and the primary treatment of wastewaters[4] were modified for this study.

Full utilization was made of the principles that were developed during the preceding swirl chamber investigations.[1-4] Background data developed by Beak Consultants, Ltd., Rexdale, Ontario, Canada, on the nature of wastewater solids and the choice of solids materials that will simulate field conditions in laboratory studies, were the basis for the choice of Petrothene and Gilsonite for the erosion solids studies.

The principle involved in the swirl unit for the erosion runoff studies was to produce swirl-action secondary-flow patterns in a rotational-velocity chamber which will separate solids from liquids in erosion runoff wastewaters. The deposited solids would be removed from the bottom of the chamber through a foul sewer connection; the clarified liquid would be discharged over a central weir, through a shaft. Monitoring of the solids contained in the bottom draw-off and in the clarified effluent would be performed by trapping and measuring these solids; the recovery efficiency would be determined by comparing the bottom material with the total solids injected into the inflow to the swirl concentration chambers by means of a feeding device.

The model previously fabricated for other swirl studies was used; it was modified to simulate, by scale-up procedures, a commercial cattle watering tank which would constitute the proposed field prototype installation. The 0.9-m (3 ft) diameter model was, therefore, on a scale of 1:4 with the 3.66-m (12 ft) cattle watering tanks available in the commercial market. Inlet facilities, interior appurtenant units, a bottom solids draw-off connection, and an overflow weir and downdraft effluent pipe were installed. The bottom of the model was first tested with a 1:15 concrete floor slope. The floor was later made flat, to represent the bottom of the commercial cattle watering tank proposed as a prototype unit that would be 0.9 m (3 ft) deep.

The Plexiglas outer shell of the swirl chamber was 13 mm (0.5 in) thick. In the center of the cylinder, an imbedded polyvinyl chloride (PVC) pipe, 15.2-cm (6 in) inside diameter, was installed to serve as the downdraft outlet for the clarified erosion water that would spill over the circular weir supported by the vertical pipe structure. The weir was maintained at a height of 0.61 m (2 ft) over the swirl concentrator chamber bottom during the entire series of tests performed with the unit.

The inlet pipe for the chamber was 15.2 cm (6 in) in diameter, set at a slope of 1:1,000. The test solids introduced into the swirl concentrator chamber, with water supplied from a constant-level tank in the laboratory's supply system, were injected into the inlet pipe by means of a vibrating feeder upstream from the swirl chamber. The rates of flow tested during the course of the studies of chamber modifications were 3, 5, and 7 l/sec (0.8, 1.3, and 1.8 gal/sec). These flows, respectively, represented the following erosion water flows in the proposed prototype:

Model Q	l/sec	3	5	7
(Model Q	gal/sec	0.8	1.3	1.8)
Prototype Q	l/sec	96	160	224
(Prototype Q	gal/sec	25	42	59)
Prototype Q	m^3/sec	0.096	0.160	0.224
(Prototype Q	ft^3/sec	3.39	5.65	7.91)
Prototype Q	m^3/day	8289.2	13815.3	19341.4
(Prototype Q	mgd	2.19	3.65	5.11)

The prototype unit, 3.66 m (12 ft) in diameter, with an effective depth of 61 cm (24 in) from the floor to the crest or lip of the overflow weir, will serve as a "flash" solids separator. The overflow pipe would be 0.67 m (2.2 ft) in diameter. The overflow liquid would experience short detention times in the chamber, as shown by the following data:

Model Q	l/sec	3	5	7
(Model Q	gal/sec	0.8	1.3	1.8)
Prototype Q	l/sec	96	160	224
(Prototype Q	mgd	2.19	3.85	5.11)
Prototype detention	sec	54.2	32.5	23.2

Grit Simulation in the Model Studies

To carry out meaningful studies of swirl concentrator chamber efficiencies in the removal of the type of soil solids contained in erosion runoff wastewaters, it was necessary to determine the type of laboratory test materials which would best simulate actual field conditions.

Gilsonite was chosen for laboratory studies because it simulated the major range of grit material that would be encountered in prototype operation. The Gilsonite had a specific gravity of 1.06. Its gradation sizes, or particle sizes, were determined and settling velocities corresponding to these sizes for the model and prototype at 1:4 scale were ascertained in accordance with techniques described in the literature, and based on irregularly shaped particles. For the range of prototype settling velocities simulated by the Gilsonite test material, the study was able to determine the particle sizes for the type of grit that would be contained in actual erosion runoff, with a specific gravity of 2.65. Because of the relatively large particle sizes which the Gilsonite simulated, it was determined that shredded Petrothene, with a specific gravity of 1.01, would best represent actual prototype grit in the laboratory model studies, and that Petrothene dust, which had a grain size range of 0.5 to 3 mm (.02 to .12 in), should be studied because it had lower settling velocities than shredded Petrothene.

Because of the ease in handling the Petrothene, this material was chosen as the simulating material in subsequent tests carried out for the purpose of exploring modified swirl chamber configurations and appurtenant structural formats that would achieve the best possible solids recovery performance. The same type of settling velocity studies made with Gilsonite were repeated for the Petrothene particles. Families of curves to define these characteristics were evolved from these study procedures. The work carried out by Beak Consultants, Ltd.,[5] in connection with previous studies of swirl units for other applications was utilized in the erosion clarification studies. The final result was the development of settling velocity distribution curves that would predict the ability of prototype installations to recover erosion solids, based on extrapolation of model tests solids at a 1:4 scale, when scaled in accordance with Froude's Law.

Some of the laboratory Petrothene dust particles, and the silts and clays that will be contained in erosion runoff waters in actual field operations were found to lie in the general range of colloids. The short-time detention of erosion runoff in a swirl concentrator could not possibly achieve removal of such fine solids and the studies made no pretention of being able to accomplish their removal.

Model Test Procedures

The tests of solids separation in the model were carried out under steady-state flows, despite the fact that any field prototype would be subjected to a wide range of flow rates during the course of any storm event. A liter (0.26 gal) of the test solids was added to the incoming flow over a 5 minute period and the model was operated for 10 minutes after the cessation of the injection period. The solids retained in the swirl chamber, the amount collected in the settling basin used to capture and gauge the effluent overflow, and the material entrained in the foul sewer settling tower were measured. Efficiencies of solids recovery were computed.

These efficiency determinations made it necessary to provide wells or basins for collecting the slurry discharge from the foul sewer and the clear water overflow from the swirl chamber. Flow was gauged in the clear effluent overflow collecting basin by means of a calibrated V-notch weir. The foul sewer settling tower was equipped with a discharge line that could be adjusted in height to modify the withdrawal of underflow from the swirl chamber at predetermined rates. Figure 3, Model Layout, shows the details of the test unit and its gauging and control facilities.

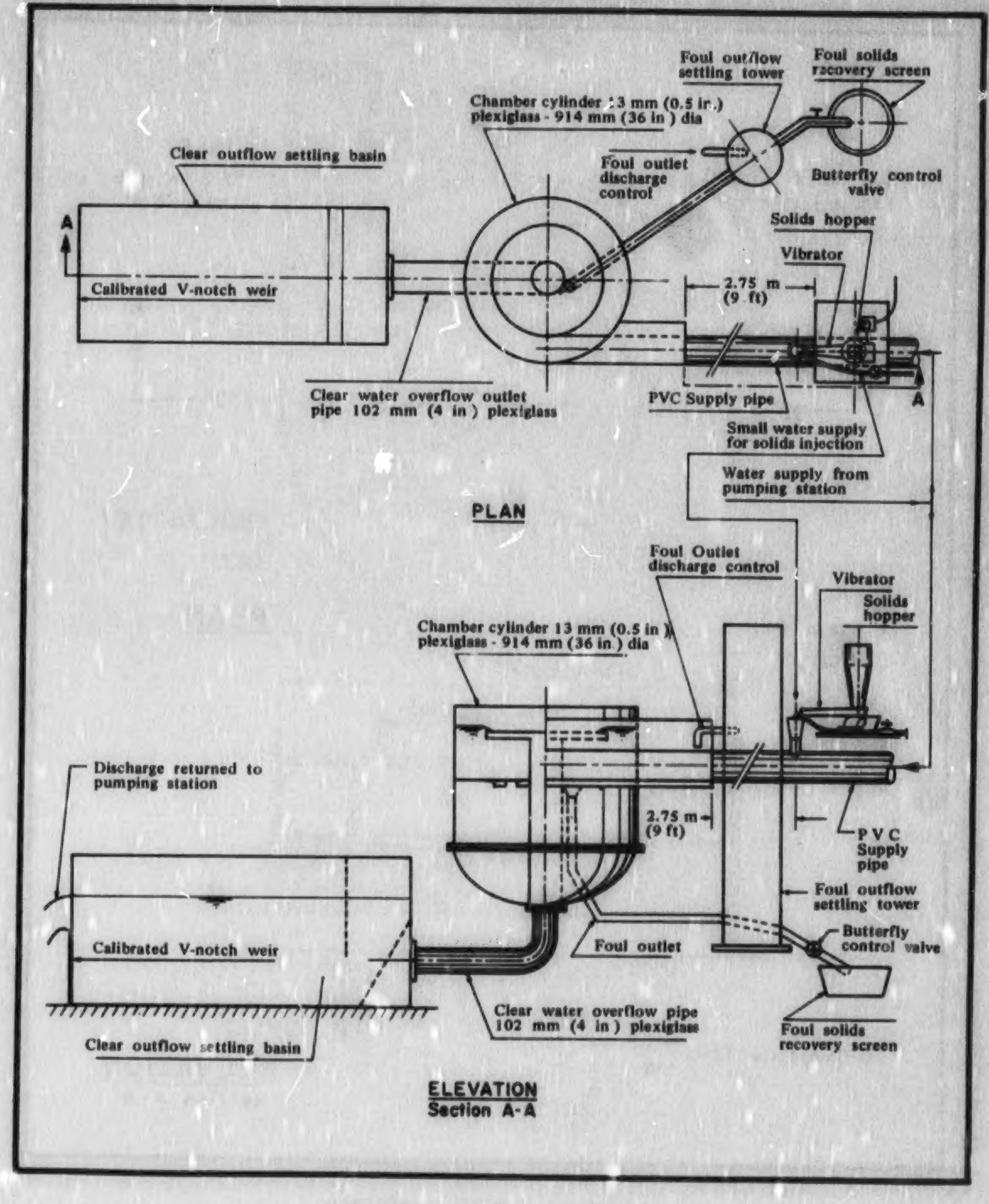
Brief tests of solids recoveries under three variations of flow rates, utilizing the original model layout, as shown in Figure 4, Original Layout for Test No. 1, with a flat disc weir, showed that the flow pattern induced in the unit was an unstable vortex, rather than a true swirl, at even the lowest flow rate. A baffle was installed to overcome this vortex action, extending from the inlet pipe to the periphery of the overflow weir, but the vortex flow pattern persisted. Flow spoilers were installed on the flat disc weir, shaped irregularly to produce better flow distribution in four quadrants of the weir. Solids recovery rates were uniformly high – approximately 95 percent – with Gilsonite. The use of the flow deflector or baffle was found to enhance solids recovery. This baffle was used in all subsequent model tests.

Extended series of twelve structural modifications were made in the swirl chamber's internal facilities, and a total of 62 specific tests were conducted, involving different flow rates, changes in foul sewer draw-off rates, and the use of different laboratory model solids – Gilsonite, shredded Petrothene and Petrothene dust. The various structural changes or configurations, the type of solids injected into the incoming flow, the rate of draw-off, and the solids recoveries achieved are tabulated in the full report of the LaSalle Hydraulic Laboratory, contained in Chapter V.

Various modifications were tested in the model. In all of the modifications, except one, the inlet size was 15.2 cm x 15.2 cm (6 in x 6 in). The modifications produced varying solids recovery efficiencies, ranging from a high of 99.5 percent to a low of 42 percent for a model flow rate of 3 l/sec (0.78 gal/sec); from 95 percent to 25 percent for model flows of 5 l/sec (1.3 gal/sec); and from 95 percent to 12 percent under flows of 7 l/sec (1.8 gal/sec). The highest consistency in solids recovery occurred at the lowest hydraulic loading rate. Gilsonite recoveries were generally higher than for the smaller and lighter Petrothene materials. The use of an inlet baffle and flow spoilers was found to improve solids recovery.

Chapter V describes the model test procedures, the nature of the model modifications and the recovery levels. It explains the influence of the weir crest and the spiral flow guide on shredded Petrothene recovery; the effect of a concentric skirt for collecting floatable solids in the swirl chamber on solids separation; the influence of weir diameter on solids recovery; the effect of chamber floor slope on chamber efficiency; the influence of continuous underflow draw-off on solids separation; and the influence of inlet size on swirl chamber performance. Similar studies were carried out with Petrothene dust, used to simulate the smaller solids particles which will enter actual prototype swirl chambers in the form of native silts and clays carried with heavier eroded materials by storm runoff waters.

As a result of the complex series of studies with model structural modifications, while handling the three types of simulated test solids at the three rates of flow applied to the laboratory model, the LaSalle Laboratory evolved rational estimates of solids recoveries in the model and developed a design procedure. Two examples of the design procedure are contained in Chapter III.


Foul outflow settling tower
Foul solids recovery screen
Chamber cylinder 13 mm (0.5 in.) plexiglass - 914 mm (36 in.) dia
Clear outflow settling basin
Foul outlet discharge control
Butterfly control valve
Solids hopper
A
Vibrator
Calibrated V-notch weir
2.75 m (9 ft)
A
Clear water overflow outlet pipe 102 mm (4 in.) plexiglass
PVC Supply pipe
Small water supply for solids injection
Water supply from pumping station
Foul Outlet discharge control
Vibrator
Solids hopper
Chamber cylinder 13 mm (0.5 in.) plexiglass - 914 mm (36 in.) dia
Discharge returned to pumping station
2.75 m (9 ft)
PVC Supply pipe
Foul outflow settling tower
Butterfly control valve
Calibrated V-notch weir
Foul outlet
Clear water overflow pipe 102 mm (4 in.) plexiglass
Foul solids recovery screen
Clear outflow settling basin

PLAN

ELEVATION
Section A-A

FIGURE 3 MODEL LAYOUT

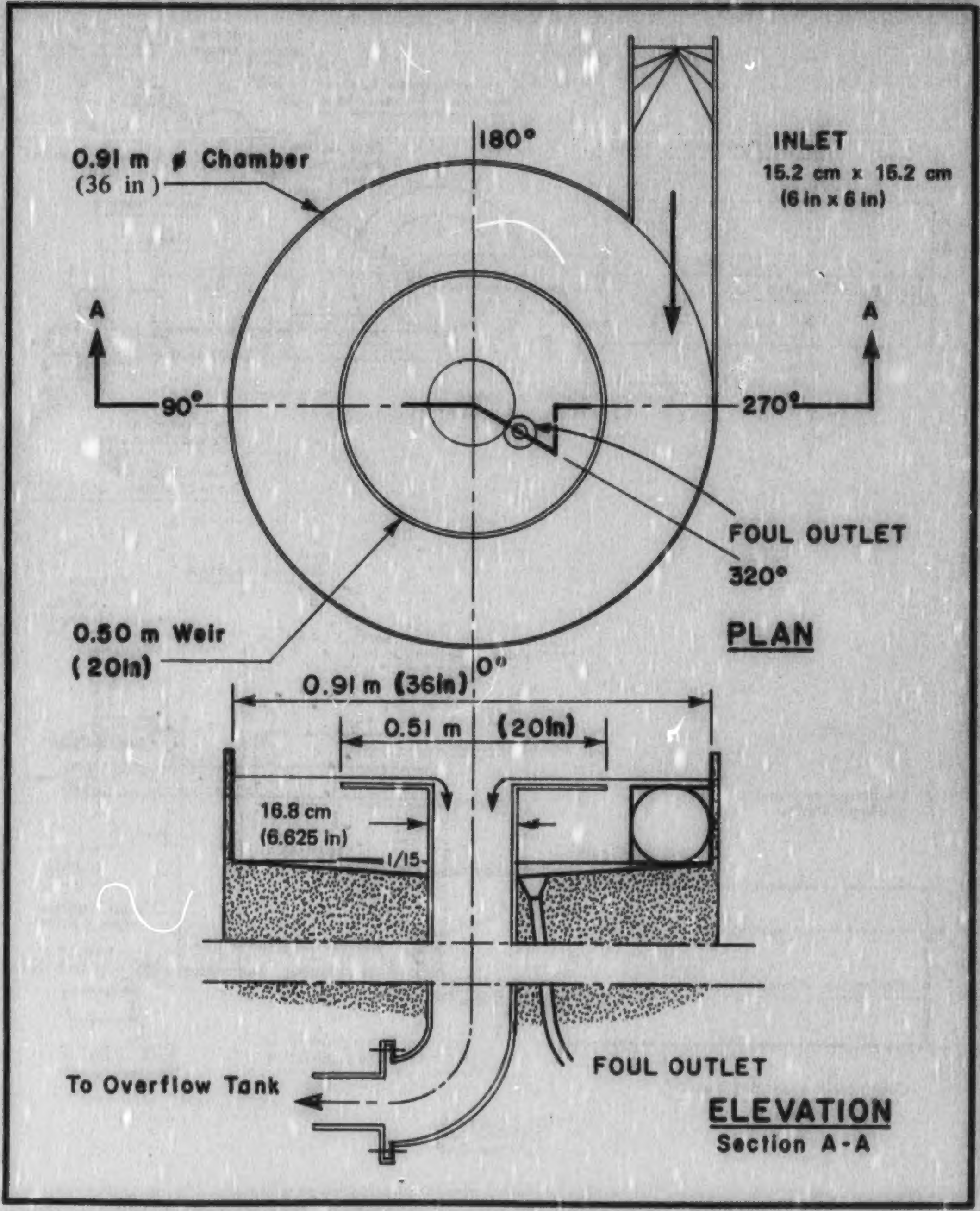
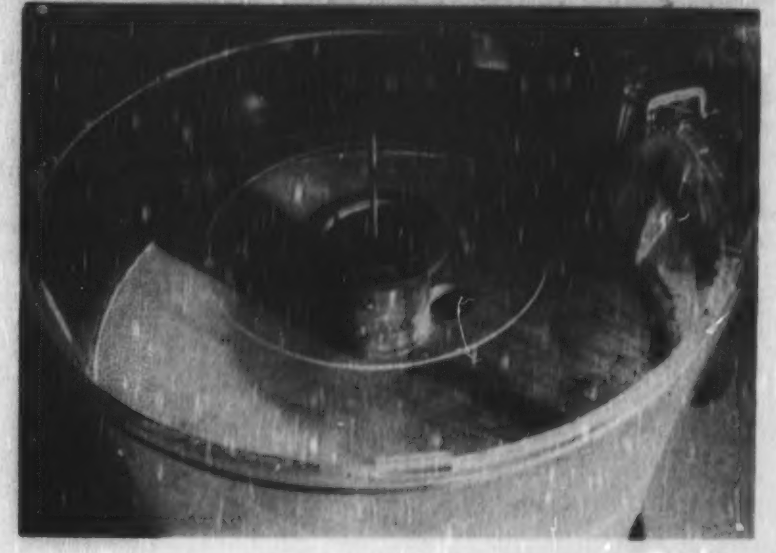
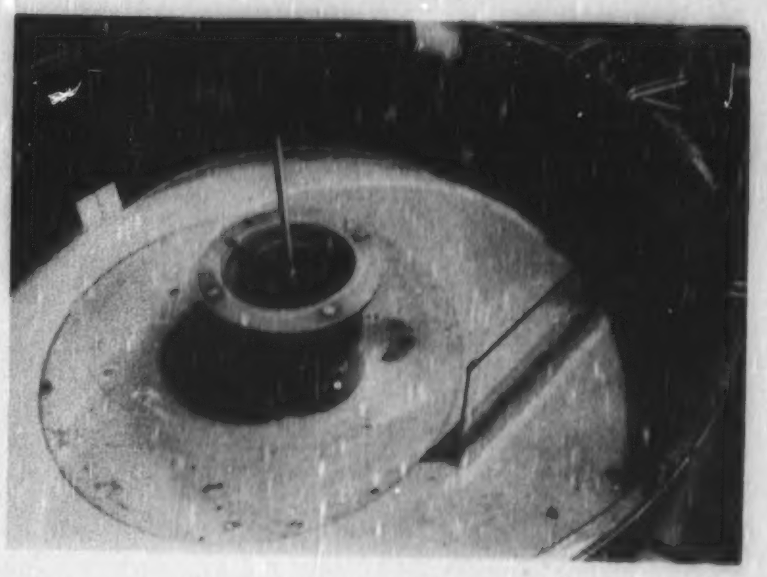

0.91 m ø Chamber
(36 in)
180°
INLET
15.2 cm x 15.2 cm
(6 in x 6 in)
A
A
90°
270°
FOUL OUTLET
320°
0.50 m Weir
(20in)
PLAN
0°
0.91 m (36in)
0.51 m (20in)
16.8 cm
(6.625 in)
1/15
FOUL OUTLET
To Overflow Tank
ELEVATION
Section A-A

FIGURE 4a ORIGINAL LAYOUT FOR TEST NO. 1



ORIGINAL LAYOUT



ORIGINAL LAYOUT WITH INLET BAFFLE

FIGURE 4b ORIGINAL LAYOUT FOR TEST NO. 1

REFERENCES

1. *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*, EPA-R2-72-008, September 1972.

2. *Relationship Between Diameter and Height for the Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator*, EPA-670/2-74-039, July 1974.

3. *The Swirl Concentrator as a Grit Separator Device*, EPA-670/2-74-026, June 1974.

4. *Swirl Concentrator as a Primary Treatment Facility*, Draft Report, 1976, EPA Grant No. 803157.

5. *Physical and Settling Characteristics of Particles in Storm and Sanitary Wastewater*, EPA-670/2-75-011, April 1975.

CHAPTER III
DESIGN FACTORS FOR SWIRL EROSION RUNOFF TREATMENT PROTOTYPES

This section on design makes frequent reference to the following listed Figures:

5 Prototype Particle Sizes Represented by Gilsonite – SG 1.06
6 Recovery Rates in Model as Function of Particle Settling Velocity and Discharge with 5 percent Draw-off
7 Recovery Rates in Model as Function of Particle Settling Velocity and Discharge with 10 percent Draw-off
8 Recovery Rates in Model as Function of Particle Settling Velocity and Discharge with 14 percent Draw-off
9 Predicted Prototype Recovery Rates with 5 percent Draw-off
10 Predicted Prototype Recovery Rates with 10 percent Draw-off
11 Predicted Prototype Recovery Rates with 14 percent Draw-off
12 General Design Dimensions

The procedure described in this section is relevant to a fixed prototype size whose scale is imposed by the use of a standard or conventional 3.66-m (12 ft) diameter cattle watering tank as the swirl chamber. The fixed scale of 1:4 determines the dimensions of the whole structure as they appear in Figure 12, General Design Dimensions.

Under operating conditions, it is assumed that the user has a situation in which the prototype discharge, Q_p, is known, as well as the prototype particle settling velocity v_{sp}, of the materials to be removed from the flow.

1. Enter Figure 9 (5 percent draw-off) where the expected discharge appears on the abscissa
2. Move up in the graph until the given particle settling velocity curve (or particle size) is found
3. Check whether or not this intersection gives an acceptable rate of recovery
4. If the recovery is not high enough, try Figures 10 or 11 in which draw-off is increased, respectively, to 10 and 14 percent of the inflow
5. If conditions are still not acceptable, even with the larger draw-off rates, then reduce the expected discharge per unit by providing multiple swirl chambers
6. If this gives too many standard 3.66-m (12 ft) units, try larger chambers, making reference directly to Figures 6, 7, and 8, the recovery curves for the 0.914-m (3 ft) diameter model
7. Select an approximate new chamber diameter, D_n and divide this by the model diameter to find the new scale:
   $l/\lambda_n = 0.914/D_n \; m = 3/D_n$ ft

Where:
   λ_n = scale factor

Next, calculate:
   new discharge scale = $1/\lambda_n^{5/2}$
   new settling velocity scale = $1/\lambda_n^{1/2}$

8. Multiply:
   $Q_p \times 1/\lambda_n^{5/2} = Q_m$ model discharge
   $v_{sp} \times 1/\lambda_n^{1/2} = v_{sm}$ model particle settling velocity
9. Go into Figures 6, 7, or 8 with these model values, interpolating as necessary between the discharge curves, to find the corresponding recovery
10. If the recovery is too low, try progressively larger chambers, each time following the procedure in steps 7, 8, and 9 above until a satisfactory recovery rate is obtained
11. Use Figure 12 to find the dimensions of the new chamber. Since the chamber shown on the figure is the standard 3.66-m (12 ft) unit studied at scale 1:4, each dimension must be multiplied by the factor $\lambda_n/4$

For purposes of illustrating the procedure for the application of this swirl unit to the problem of soil erosion, two examples will be given. The first is based upon an engineering approach where a permanent facility is to be designed for a required level of efficiency. The second example is for the case where a developer must provide *temporary* facilities at a construction site.

Permanent Erosion Control Facility

For a permanent erosion control facility the use of the swirl concentrator may be envisioned as an auxiliary treatment device

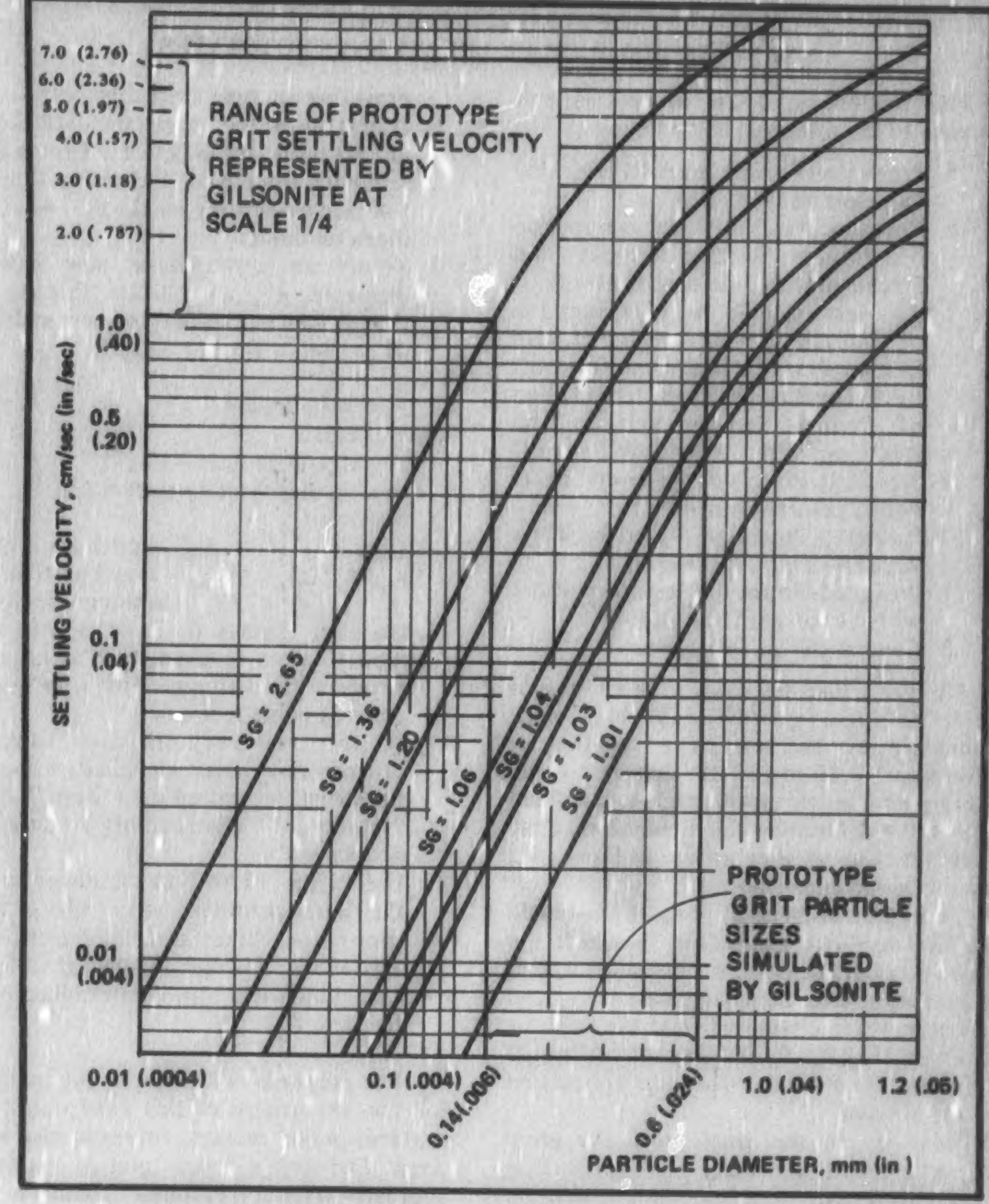


FIGURE 5 PROTOTYPE PARTICLE SIZES REPRESENTED BY GILSONITE – SG 1.06

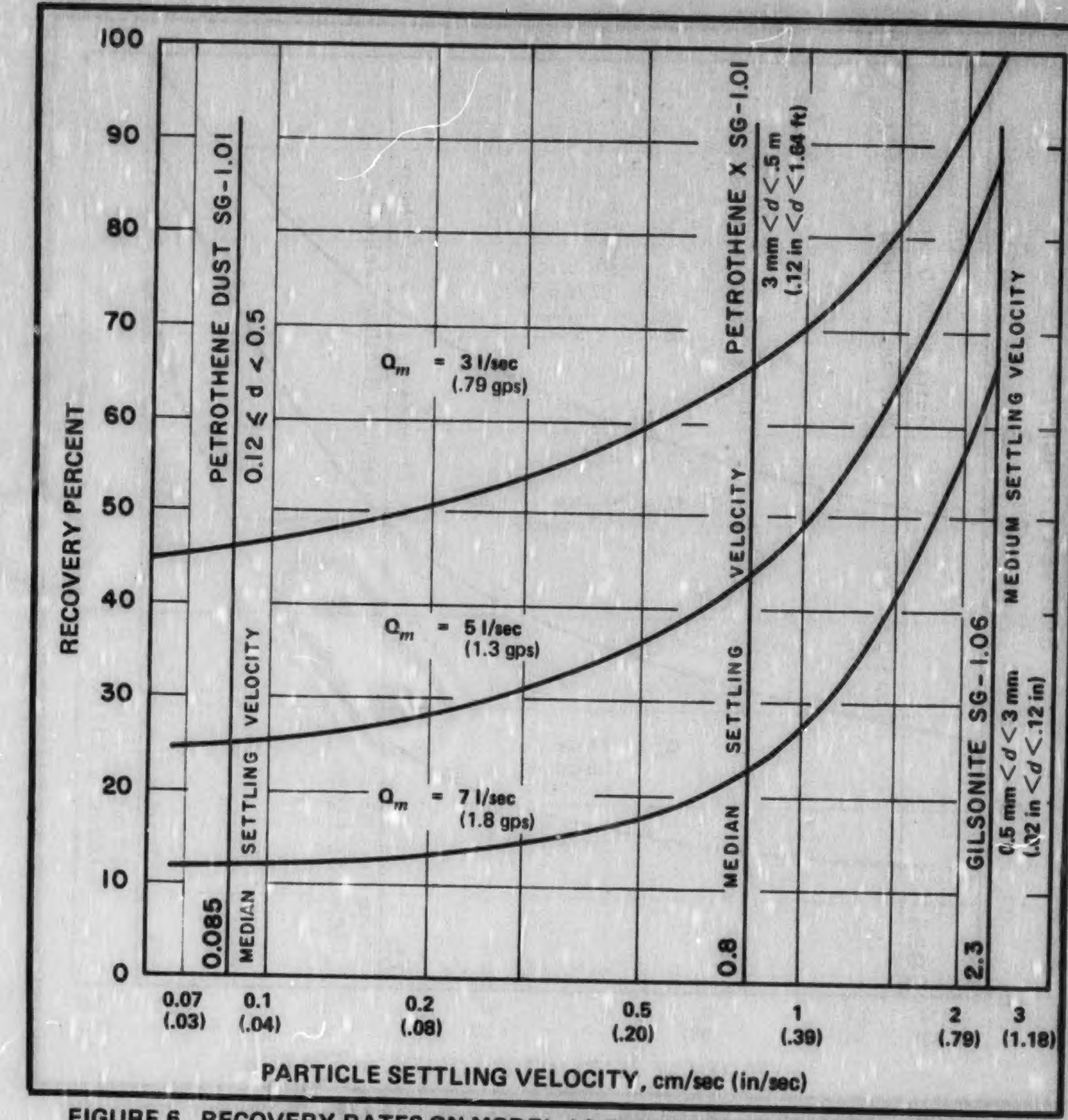


FIGURE 6 RECOVERY RATES ON MODEL AS FUNCTION OF PARTICLE SETTLING VELOCITY AND DISCHARGE WITH 5 PERCENT DRAW-OFF

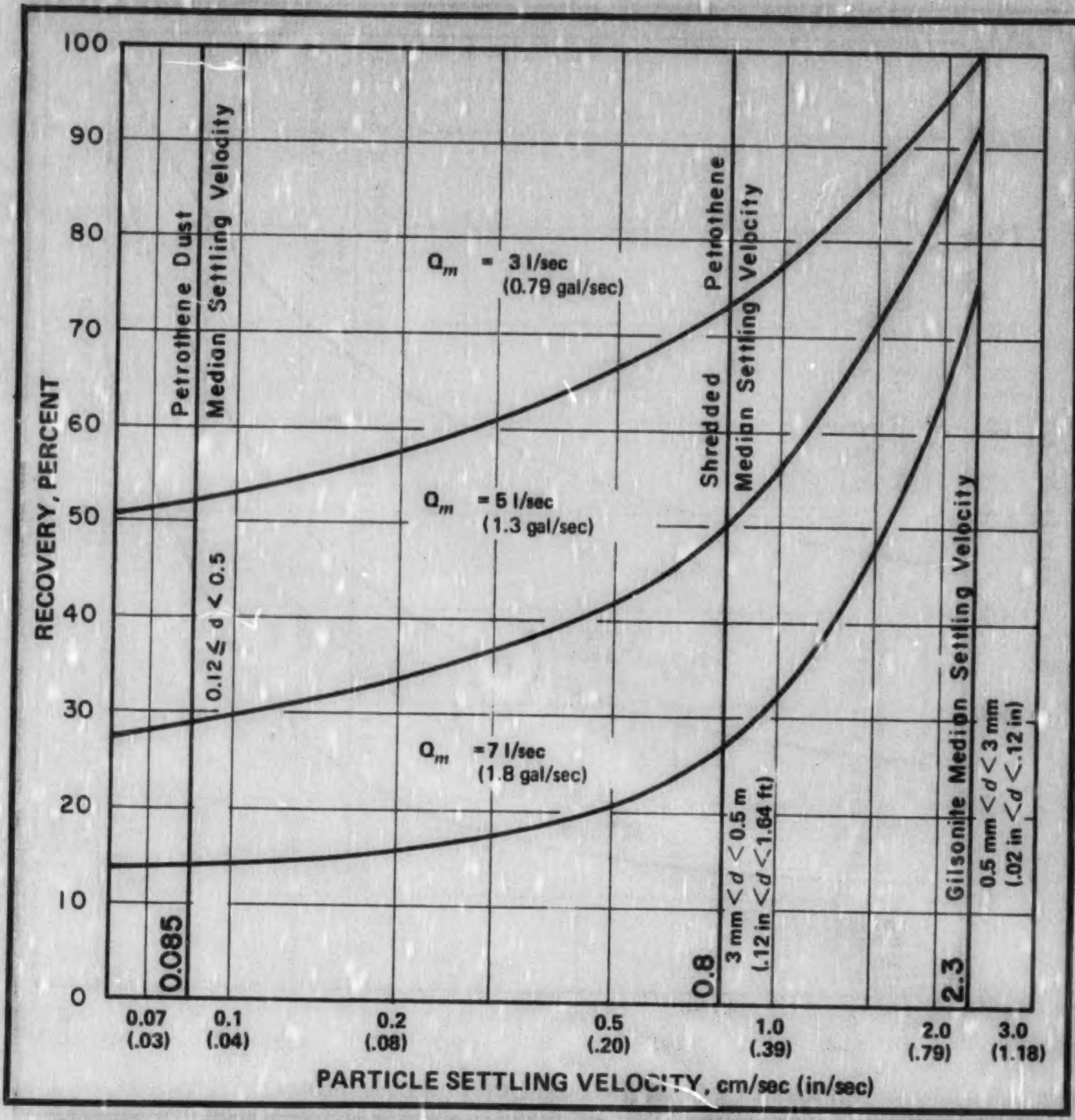


FIGURE 7 RECOVERY RATES ON MODEL AS FUNCTION OF PARTICLE SETTLING VELOCITY AND DISCHARGE WITH 10 PERCENT DRAW-OFF

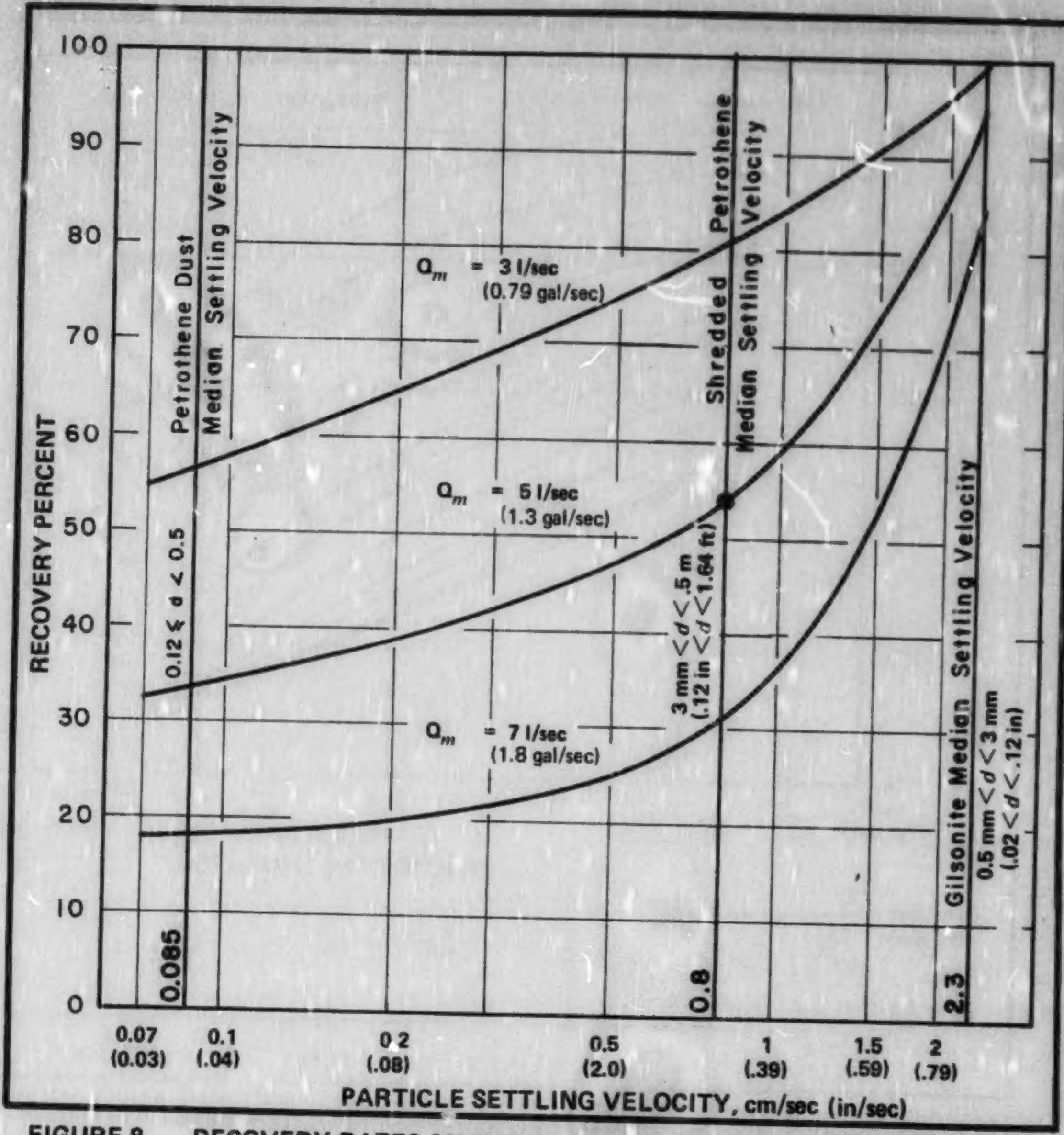


FIGURE 8 RECOVERY RATES ON MODEL AS FUNCTION OF PARTICLE SETTLING VELOCITY AND DISCHARGE WITH 14 PERCENT DRAW-OFF

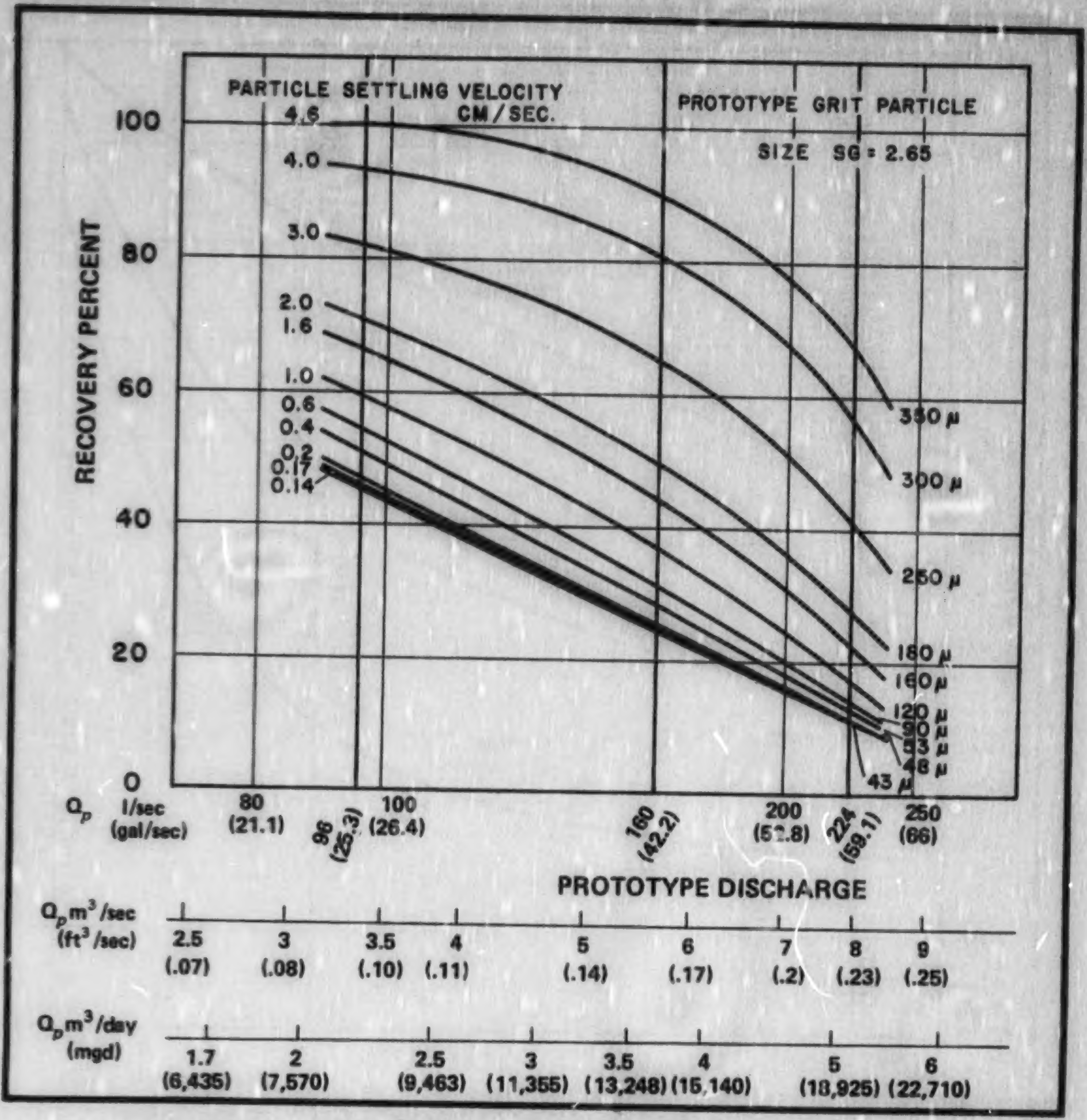


FIGURE 9 PREDICTED PROTOTYPE RECOVERY RATES WITH 5 PERCENT DRAW-OFF

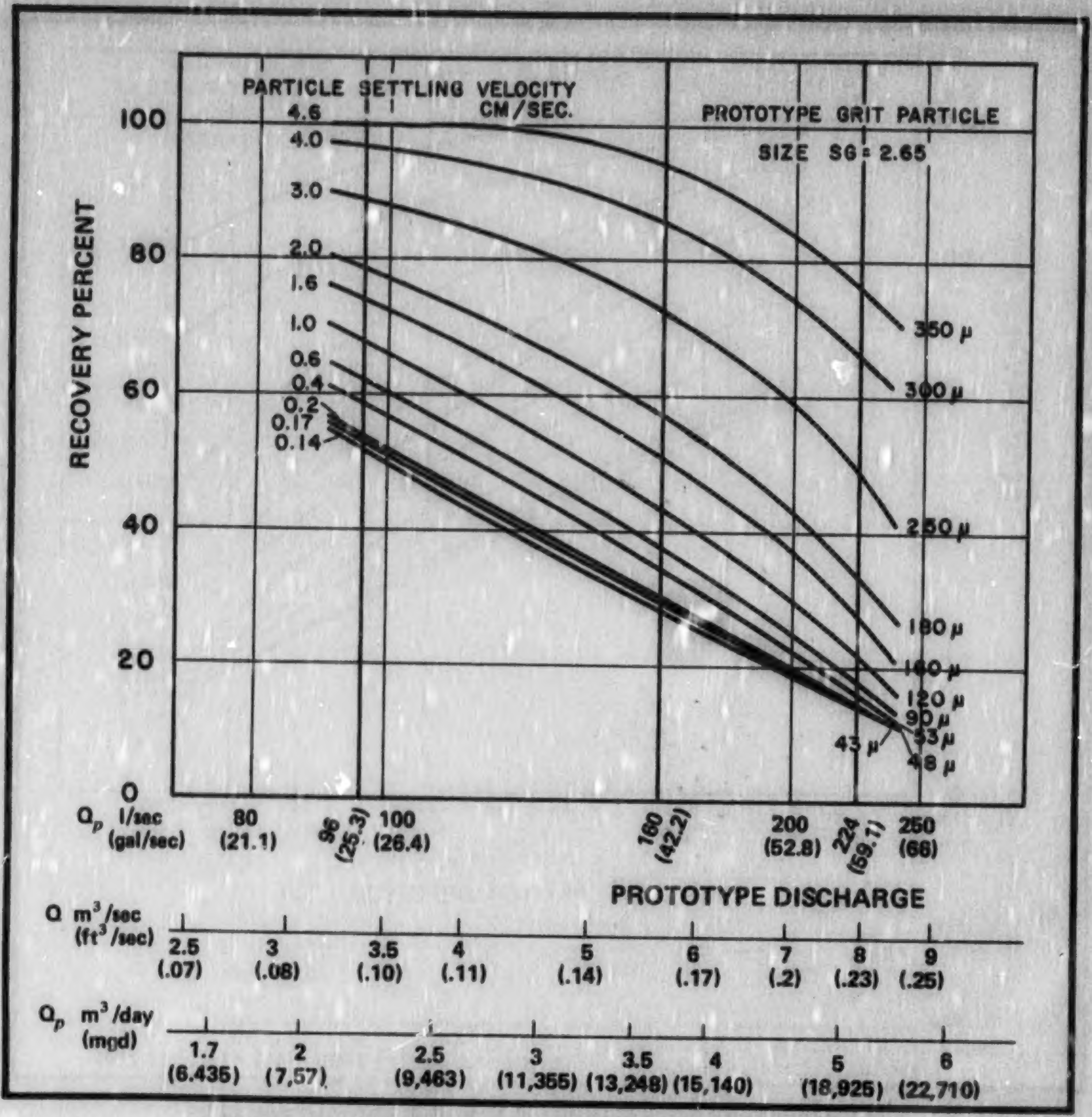


FIGURE 10 PREDICTED PROTOTYPE RECOVERY RATES WITH 10 PERCENT DRAW-OFF
3.6 m (12 ft) Diameter Chamber

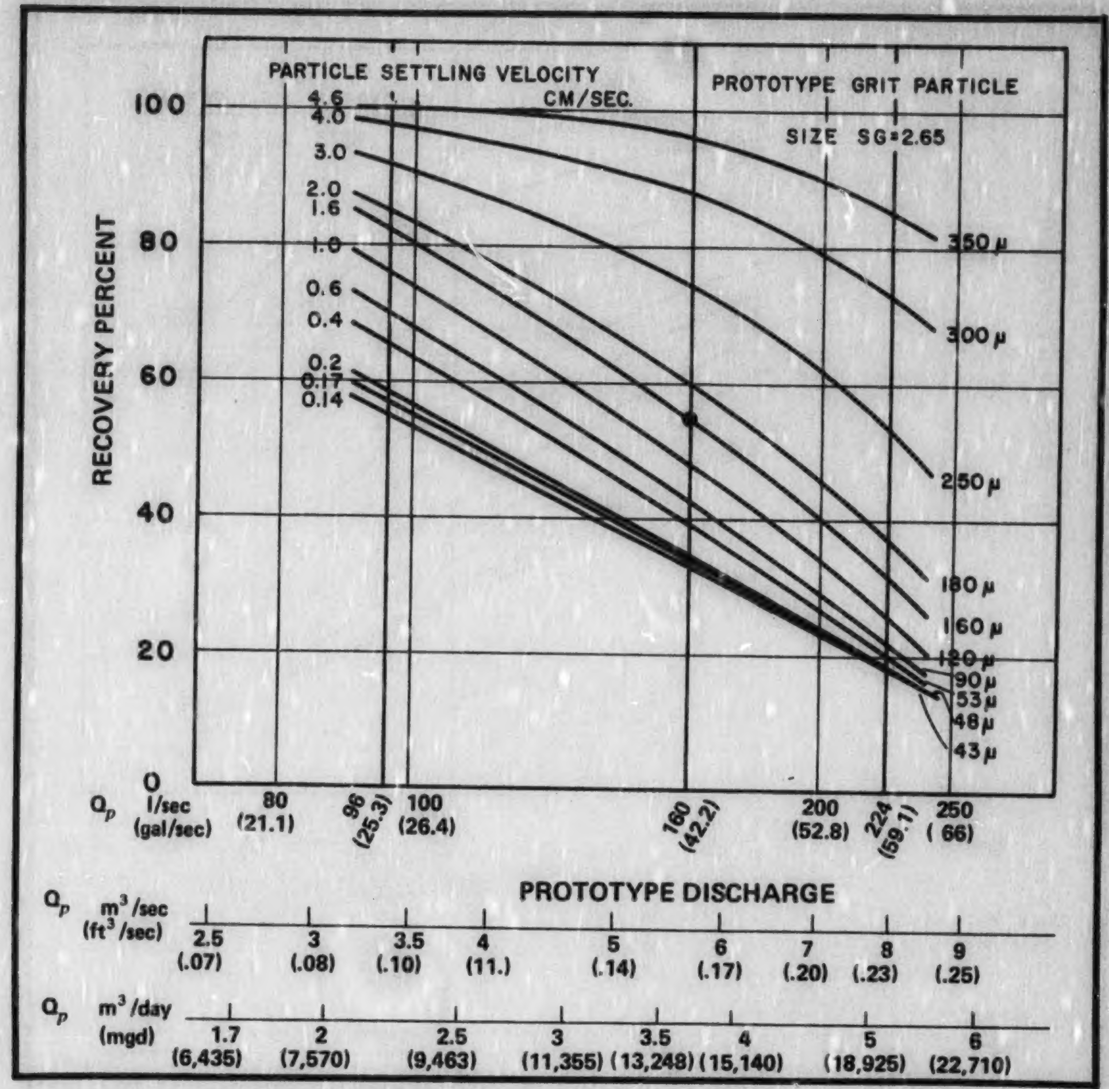


FIGURE 11 PREDICTED PROTOTYPE RECOVERY RATES WITH 14 PERCENT DRAW-OFF
3.6 m (12 ft) Diameter Chamber

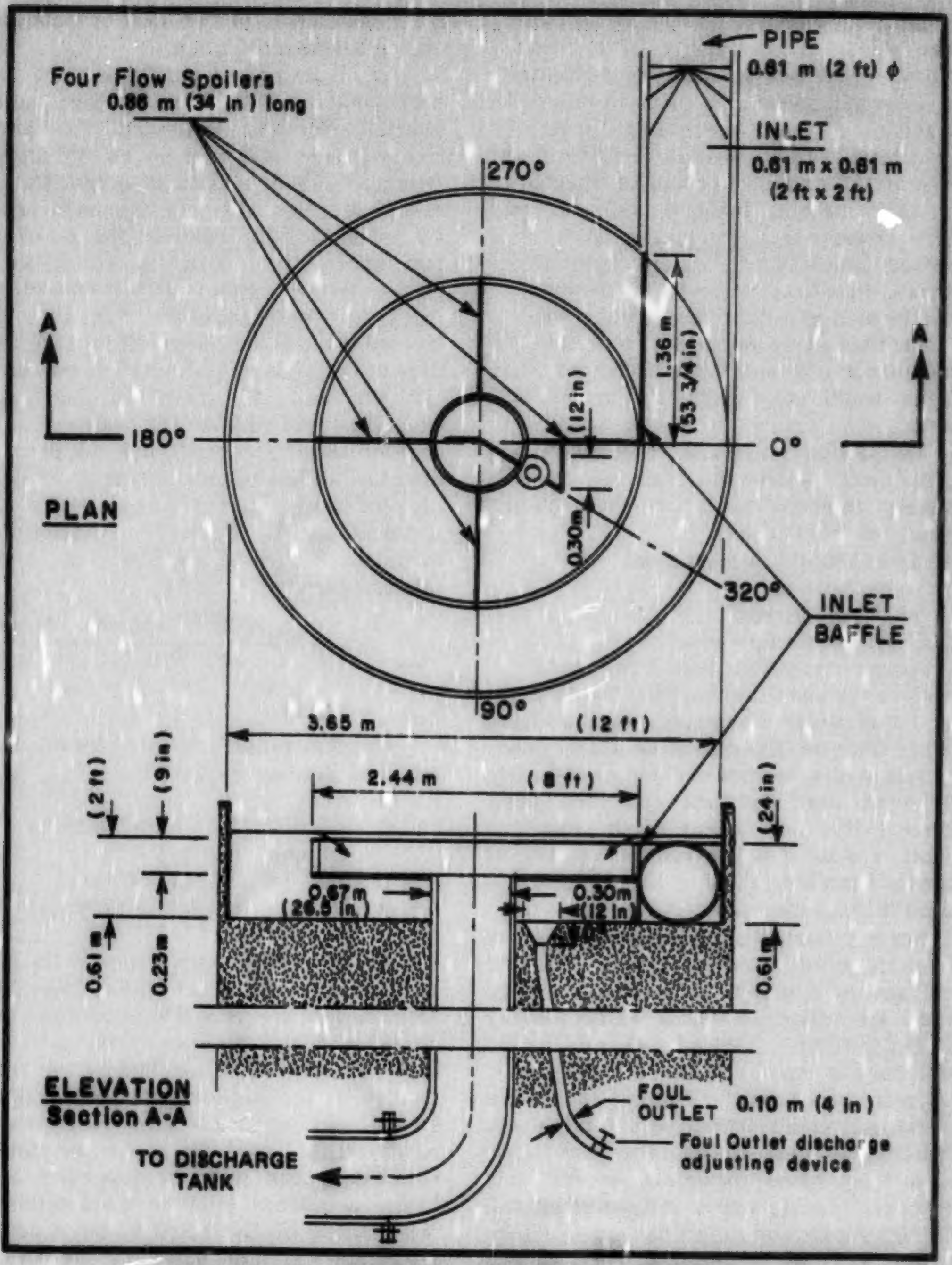

PIPE
0.61 m (2 ft) ϕ
Four Flow Spoilers
0.86 m (34 in) long
INLET
0.61 m x 0.61 m
(2 ft x 2 ft)
270°
A
A
1.36 m
(53 3/4 in)
(12 in)
180°
0°
PLAN
0.30m
320°
INLET
BAFFLE
90°
3.65 m
(12 ft)
2.44 m
(8 ft)
(2 ft)
(9 in)
(24 in)
0.67m
(26.5 in)
0.30m
(12 in)
0.61 m
0.23 m
0.61m
ELEVATION
Section A-A
FOUL
OUTLET
0.10 m (4 in)
Foul Outlet discharge
adjusting device
TO DISCHARGE
TANK

FIGURE 12 GENERAL DESIGN DIMENSIONS
SCALE: 1/4

installed ahead of a stormwater retention-detention facility. The primary purpose of the unit would be to concentrate the larger soil particles in order to retard the siltation of the retention facility or downstream receiving waters. To this end, the concentrated underflow could be directed to a readily cleaned auxiliary sediment trap where conventional equipment, such as a backhoe, Gradall,® or even a bucket loader – assuming that the area could be dewatered – could be used to remove the collected soil.

Such a facility would minimize the total maintenance cost and improve the efficiency of the major storage facility or receiving waters.

The design procedure is developed in accordance with the various elements normally required for a complete system. These elements are:

- Hydrological Considerations
- Solids Analysis
- Swirl Unit Design
- Efficiency Computation
- Assessment of Retention Volumes
- Other Design Considerations and Details

A typical site situation is shown in Figure 2, Flow Diagram. This plan shows a large drainage area with a stormwater retention facility. The swirl unit and soil collection pond intercept this flow ahead of the retention facility ponds. It is assumed that all runoff from the basin is detained on the property and passed through the swirl unit or units.

For purposes of determining the quantity of runoff to be expected from the drainage area, any of a number of methods can be used. In references to a recent survey conducted by APWA[6] rainfall runoff predictions in practice are based primarily on unit hydrographs and the Rational Method. In general, maximum erosion will occur under conditions of peak runoff. The peak storm which may cause maximum erosion may never occur during a given interval of interest in design for erosion runoff control. Common design practice for drainage structures is based on a rainfall intensity which occurs frequently. A commonly used rainfall intensity is a 10-year recurrence interval, although in many cases the choice of a design rainfall is determined for a specific project by the requirements of the local or state public agency having jurisdiction.

As an example, let it be assumed that a 80.9 hectare (200 acre) drainage basin is selected. For this watershed, the time of concentration is found to be 45 minutes. Assuming that it is desired to find the peak runoff at a time when equilibrium conditions are established for this site, the duration of the storm is taken as the time of concentration. From a duration-intensity relation established for this site, it is determined that the intensity is 1.27 cm/hr (0.5 in/hr). Further information on the site indicates that 20 percent of the basin is occupied by buildings for which a runoff coefficient of 0.9 is selected; 15 percent is roadways with a runoff coefficient of 0.9; and the remainder is grassed yard areas for which a runoff coefficient of 0.3 is assumed. An average coefficient for this site can be calculated as:

$$C_{ave} = \frac{(40 \text{ ac} + 30 \text{ ac}) \times 0.9 + 130 \text{ ac} \times 0.3}{200}$$

$$C_{ave} = 0.51$$

The peak runoff calculated for this storm, using the Rational Method, is:

$$Q = CiA$$

$$Q = 0.51\ (1.27 \text{ cm/hr})\ 80.9 \text{ ha} = 52.4 \text{ cm-ha/hr}$$

$$= 52.4 \times 27.8 = 1{,}460 \text{ l/sec}$$

$$Q = 0.51\ (0.5 \text{ in/hr})\ (200 \text{ ac}) = 51 \text{ ft}^3/\text{sec}$$

This flow will be used later as the inflow to the swirl erosion control facility. More accurate predictions of the proper intensity of rainfall upon which to predict the most severe eroding rainfall to be handled by this erosion control device can only be obtained after several field experiences have been evaluated. Any method used prior to the time of verification can only be subjective and is highly dependent upon local conditions. In many areas of the country, more accurate information is available for the prediction of times of concentration and peak rainfall intensities.

A second part of the hydrologic analysis required to design an erosion control facility involves an estimate of the peak volume of runoff for a given storm. This volume will be used to size the retention pond and the soil collector pond. Obviously, the high-intensity, short-duration storm may contribute a high flow rate for a short period, but it would represent only a portion of the total volume of runoff that could be expected from a storm of longer duration. With reference to a set of intensity-duration curves, it was observed that for the same recurrence frequency that was used in the determination of the peak flow rates, a storm of longer duration of 4 hours would yield an intensity of 1.02 cm/hr (0.4 in/hr). The peak rate of flow for this storm can be estimated in the same manner as previously:

$$Q = 0.51\ (1.02\ \text{cm/hr})\ 80.9\ \text{ha} = 42.1\ \text{cm-ha/hr}$$
$$= 42.1 \times 27.8 = 1170\ \text{l/sec}$$
$$Q = CiA = 0.51\ (0.4\ \text{in/hr})\ 200\ \text{ac}$$
$$= 40.8\ \text{ft}^3/\text{sec}$$

The use of the Rational Method C factor will result in an estimate of a larger flow than would ordinarily be anticipated for all but the most intense storms.

Perhaps the most accurate method for determining the volume of runoff would be to integrate the area on a hydrograph determined for this watershed. For the determination of this volume, the use of a unit hydrograph would be advantageous.

Various other methods are also available for computing the storage volume necessary to hold the total runoff. Using one of these methods, assume the resultant volume is 8,420 m^3 (297,226 ft^3). This yields a larger volume than that associated with the short-duration, higher-intensity storm.

The final hydrologic determination deals with an annual estimate of the total quantity of sediment to be expected. This volume will be used to estimate the total amount of settleable solids to be collected in the two ponds. Reference to a chart of expected annual rainfall in the project area, will provide the annual precipitation rate. It is probably not necessary to reduce these values for precipitation occurring as snowfall for the purpose of this estimate. Assume that this value is 76.2 cm (30 in) per year. It is also assumed that the area of the two retention ponds is small compared to the total area, although this fact may not always be true. The runoff volume per year is then:

$$V = 0.51\ (76.2\ \frac{\text{cm}}{\text{yr}}) \times \frac{1\ \text{m}}{100\ \text{cm}} \times 80.9\ \text{ha}$$
$$\times \frac{10{,}000\ \text{m}^2}{\text{ha}} = 314{,}000\ \text{m}^3/\text{yr}$$
$$V = 0.51\ (30\ \text{in/yr}) \times \frac{1\ \text{ft}}{12\ \text{in}}$$
$$\times\ 200\ \text{ac} \times 43{,}500\ \frac{\text{ft}^2}{\text{ac}}$$
$$= 11{,}100{,}000\ \text{ft}^3/\text{yr} = 411{,}000\ \text{yd}^3/\text{yr}$$

In summary, these three calculated quantities will be used in the following manner:

a. The peak runoff rate will be used to size the swirl concentrator erosion control device or devices, the main drainage trench conducting flow to the device and any inlet conduit that must be used.
b. The single storm volume will be used to size the two retention basins.
c. The annual storm runoff volume will be used to estimate the quantity of settleable material which will accumulate in the retention basins. This represents material for which storage capacity must be provided within the pond, or the volume of material which must be removed.

Solids Analysis

The next step in the design procedure is to determine the quantity, type and size of material that is likely to be found in stormwater runoff at this site. Table 1, Sieve Analysis, presents an analysis of a sample of storm runoff from an erosion site which was sieved and separated into groups having similar specific gravities. Such an analysis is used to determine the type and specific gravities of the material present, thus enabling a reasonable estimate of the type and quantity of material that can be removed in a swirl erosion control unit. This example should be viewed as merely an indication of the type of investigation that should be conducted. There may be many sites for

TABLE 1
SIEVE ANALYSIS

Sieve Size	Size	Material Retained	Percent Retained	SG/2.65	Percent Retained According to SG SG/1.20	SG/1.01
	mm (in)	gm (oz)				
10	2.00 (.08)	4.0 (0.14)	1.14	1.04	. . .	0.1
20	0.84 (.03)	6.5 (0.23)	1.86	1.06	. . .	0.2
60	0.25 (.01)	39.0(1.4)	11.14	8.64	2.0	* * * * 0.5
100	0.149(.006)	100.5(3.5)	28.71	23.61	5.0	0.1
120	0.125(.005)	77.0(2.7)	22.00	21.00	* * * * 1.0	. . .
200	0.074(.003)	44.0(1.5)	12.57	12.07	0.5	. . .
PAN	- - - -	79.0(2.8)	22.57	22.57	. . .	. . .
			TOTAL	90.59	8.5	0.9

which more elaborate and complete analyses may be desirable.

Assuming that it is desirable to remove as much settleable material as possible in the swirl unit, the smallest particle that is predicted from the model studies to be removed is a grit particle, specific gravity 2.65, 43 microns in diameter, having a settling velocity of 0.14 cm/sec (0.055 in/sec) as shown in Figure 11. A design incorporating the removal of this size of grit particle will also remove larger size particles of lighter weight. For example, with reference to Figure 5, a particle of specific gravity 2.65 and a settling velocity of 0.14 cm/sec (0.055 in/sec) is 0.045 mm (.002 in) in diameter. For the same settling velocity a particle of SG 1.20 with a diameter of 0.14 mm (0.006 in) will settle at the same rate as a particle having a SG of 1.01 (organic material) with a diameter of 0.6 mm (0.02 in). Similar settling velocities can be obtained from Figure 13, Prototype Particle Sizes Represented by Petrothene – SG. 1.01. Particle sizes larger in diameter than those quoted are expected to be removed. In the sieve analysis shown in Table 1, the material expected to be removed in part by the swirl concentrator is shown in the specific gravity columns at the right side of the table above the asterisk marks, considering that the settling velocity is 0.14 cm/sec (0.055 in/sec) for a particle having an SG of 2.65.

Hydrometer analysis using pan material, or 22.5 percent of the total sample, showed:

Percent particle size greater than 0.052 mm (0.002 in) – 16.0%

Percent particle size less than 0.052 mm (0.002 in) – 6.57 %

From design data, using a particle settling velocity of 0.14 cm/sec (0.055 in/sec) it was determined that the following percent of material will be subject to removal in the swirl chamber:

SG 2.65 90.59 - 6.57 = 84.02%
SG 1.20 8.5 - 1.5 = 7.0 %
SG 1.01 0.9 - 0.6 = 0.3 %

(These quantities are shown in the table as the percent in each SG column above the asterisk)

Total material subject to removal by swirl concentrator – 91.33%

Total material not subject to removal – 8.67%

The removable material percent shown here will be multiplied by the recovery efficiencies of the chamber from the design curves, Figures 9, 10, or 11.

Swirl Unit Design:

From an earlier section it had been determined that the peak design runoff flow rate is 1,460 l/sec (51 ft^3/sec). With reference to Figure 11, it is seen that for a 12-foot-diameter chamber, the highest efficiency is obtained when the flow rate does not exceed 96 l/sec (3.4 ft^3/sec). Dividing the flow by a factor of 15 would give 97 l/sec (3.4 ft^3/sec) as the design flow for each of the chambers, and this flow in Figure 11 is at the left end of the curve, at the highest possible removal efficiency for this particle size. The use of 15 chambers would also mean that

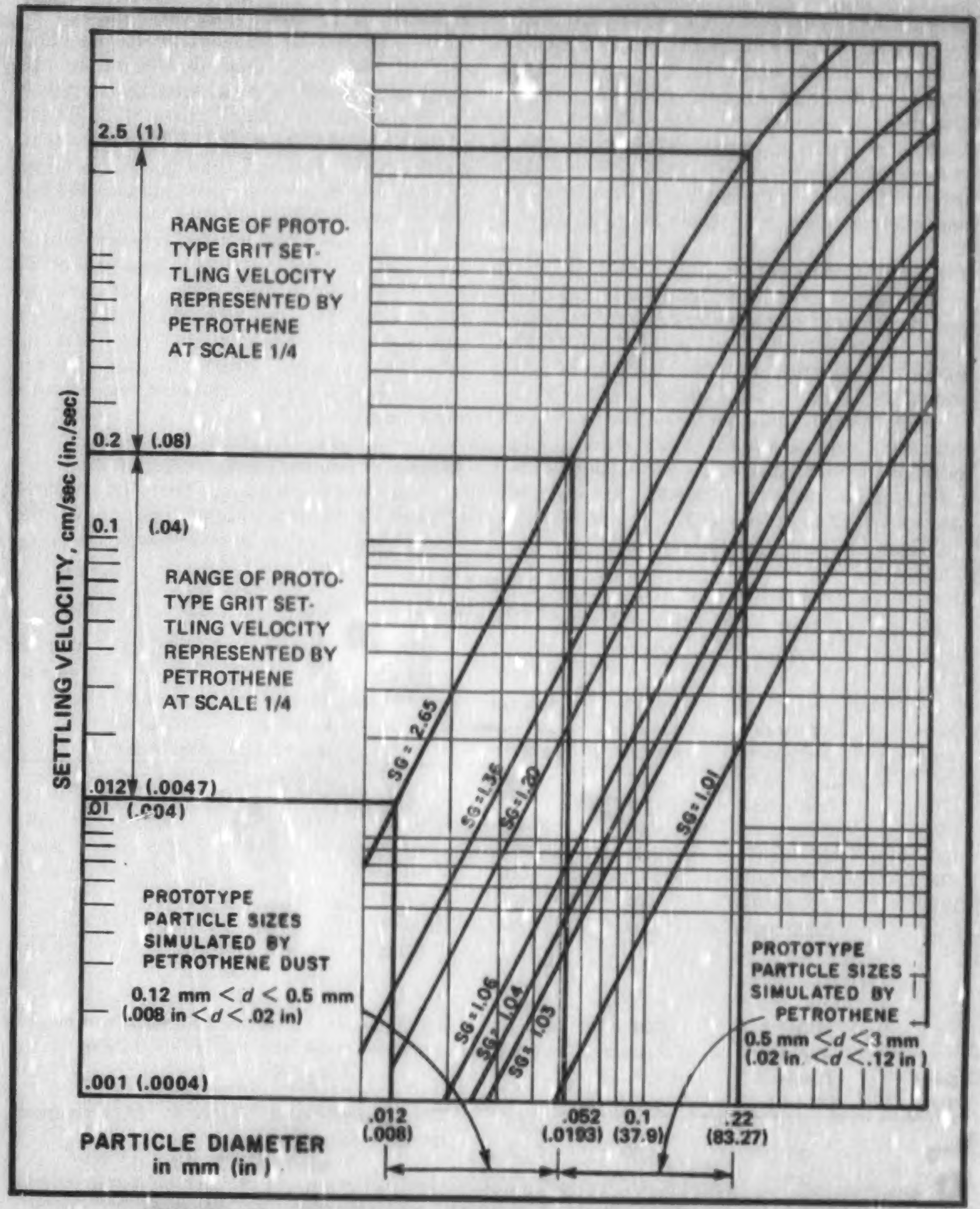


FIGURE 13 PROTOTYPE PARTICLE SIZES REPRESENTED BY PETROTHENE – SG – 1.01

higher intensity storms could still be handled by these chambers with only a small reduction in efficiency. In fact, the design runoff could be more than doubled in each chamber. It should be noted that if the 14-percent draw-off rate is excessive for the volume of storage desired, Figures 9 and 10 should be used with smaller draw-off rates and corresponding reductions in efficiencies.

Efficiency Computation

Using the efficiencies given in Figure 11 and the percent of each size material given in Table 1, the efficiency of the 3.65-m (12 ft) diameter chamber can be determined, as shown in Table 2, Swirl Efficiency Analysis.

For specific gravities less than 2.65, an equivalent particle size for that particle can be obtained from Figure 5. As an example with reference to Table 2, a particle for specific gravity of 1.20 is taken as 0.25 mm (0.01 in). In Figure 5, find this size along the abscissa: go vertically upward to the curve marked SG 1.20, then left or horizontally to the curve marked SG 2.65, then downward to the abscissa. The values read, settling velocity is 0.5 cm/sec (0.19 in/sec) for a SG 1.20 and particle size 0.25 mm (0.01 in); an equivalent particle of SG 2.65 having this settling velocity is a particle of 0.082 mm (0.003 in). Refer back to Figure 11 for this size particle of 82 microns and settling velocity of 0.5 cm/sec (0.019 in/sec). For a flow rate of 97 l/sec (3.4 ft^3/sec), this yields an efficiency of 69 percent. This procedure is continued for other particle sizes. It is seen that an efficiency of 68.76 percent is predicted for this material if a set of 15 swirl concentrators were used.

Alternate Chamber Design Investigation

The design discharge, *Q* is 1,460 l/sec (51 ft^3/sec). With reference to Figure 8, the smallest particle shown is one having a settling

TABLE 2
SWIRL EFFICIENCY ANALYSIS

Sieve Size	COL. 1 Particle Size mm(in)	COL. 2 Percent Retained SG 2.65	COL. 3 Percent Eff. from Fig. 11	COL. 3 $= \frac{1 \times 2}{100}$	COL. 4 Percent Retained SG 1.20	COL. 5 Percent Eff. from Fig. 11 & 5	COL. 6 = 4 x 5
10	2.00 (.08)	1.04	100	1.04	– –	– –	– –
20	0.84 (.03)	1.66	100	1.66	– –	– –	– –
60	0.25 (.01)	8.64	92	7.95	2.0	69	1.38
100	0.149(.006)	23.61	82	19.36	5.0	56	2.8
120	0.125(.005)	21.00	79	16.59	1.0	– –	– –
200	0.074(.003)	12.07	69	8.32	0.5	– –	– –
HYD	0.052(.002)	16.00	59	9.44			
				64.36			4.18

Sieve Size	COL. 7 Percent Retained SG 1.01	COL. 8 Percent Eff. from Fig. 5 & 11	COL. 9 = 7 X 8
10	0.1		0.1
20	0.2	60	0.12
60	0.5	– –	– –
100	0.1	– –	– –
120	– –	– –	– –
200	– –	– –	– –
HYD	– –	– –	– –
			0.22

Total percent of removal material removed in swirl unit = 64.36% + 4.18% + 0.22%
= 68.76%

Total percent of settleable material removed by swirl concentrator
= 68.76% x 91.3% = 62.7%

velocity of 0.07 cm/sec (0.03 in/sec). For other draw-off rates, Figure 6 or 7 could be used for 5 percent or 10 percent draw-off, respectively. Figure 8 was selected since the best recovery occurred with a draw-off of 14 percent. Assume that four prototype chambers will be used, each having a diameter of 6.4 m (21 ft). This sets the model scale at:

$$\lambda = L_p/L_m = 6.4 \text{ m}/0.914 \text{ m } (21 \text{ ft}/3 \text{ft}) = 7$$

From the Froude Law the velocities of settlement can be related as:

$$v_{sp}/v_{sm} = \sqrt{L_p/L_m} = \sqrt{7} = 2.65$$

The model discharge is also found from the Froude Law as:

$$Q_p/Q_m = (L_p/L_m)^{5/2} = (7)^{5/2} = 129.64$$

$$Q_m = Q_p/129.64 = \frac{1{,}460}{4} \text{ x } \frac{1}{129.64} = 2.81 \text{ l/s}$$

Referring now to Figure 8, the discharge line for 2.81 l/sec (0.74 gal/sec) must be interpolated between the 3 l/sec (0.80 gal/sec) line and zero at 100 percent recovery. Assume it crosses the 0.07 cm/sec (0.03 in/sec) settling velocity line at about 60 percent recovery.

This model settling velocity corresponds to a prototype settling velocity of:

0.07 cm/sec x 2.65 = 0.185 cm/sec (0.073 in/sec)

From Figure 5, this gives a particle size of 0.05 mm (0.002 in) for SG = 2.65 material.

Another approach to selecting the chamber size would be to decide to use 3 l/sec (.106 ft^3/sec) in either Figures 6, 7, or 8 as the required rate of recovery curve. Working with Froude's Law, the scale can be found:

$$\lambda^{5/2} = Q_p/Q_m = \frac{1{,}460}{4} \text{ x } \frac{1}{3} = 121.7$$

$$\lambda = 6.83$$

The corresponding chamber diameter would be:

$$d = 6.83 \text{ x } 0.94 \text{ m} = 6.4 \text{ m } (21 \text{ ft})$$

The velocity scale becomes:

$$\frac{1}{\sqrt{\lambda}} = \frac{1}{\sqrt{6.83}} = \frac{1}{2.61}$$

It is now possible to prepare a new operating curve for this unit at the 365- l/sec (12.89 ft^3/sec) discharge by taking recovery rates from the 3 l/sec (0.8 gal/sec) in either Figures 6, 7, or 8, and multiplying the corresponding settling values by 2.61 to find the settling velocities that would be recovered.

The dimensions of the individual swirl units would be λ/4, or 6.83/4, or 1.70 times, for each dimension shown in Figure 12, since the dimensions shown in Figure 12 are for a model scale of 1:4.

Keeping the same scale relations, similar calculations could be carried out for the 5 and 7 l/sec (1.32 and 1.85 gal/sec) lines on Figures 6, 7, and 8. The resulting three operating curves could then be interpolated at selected settling velocity values to yield data that could be plotted in the same manner as shown in Figures 9, 10, and 11 but for the chosen chamber size.

In addition to the settleable solids, a considerable quantity of light suspended or colloidal solids is present in storm erosion runoff. It is anticipated that none of these lighter solids would be removed in the swirl unit, but there would be almost complete removal of such solids in the second retention pond if sufficient settlement time occurred between storms.

Assessment of Retention Volumes

The volume per storm was determined to be 8,420 m^3 (297,527 ft^3/sec). Using an underflow draw-off rate of 14 percent, the volume to be handled in the underflow effluent or primary pond is:

8,420 m^3 (297,527 ft^3) x 0.14 = 1,180 m^3 (41,696 ft^3) while the second retention pond would be:

8,420 m^3 (297,527 ft^3) – 1,180 m^3 (41,696 ft^3) = 7,240 m^3 (255,830 ft^3).

These pond volumes are sized to retain all of the treated runoff from the design storm. In practice, most ponds are designed to allow flow-through for the normal runoff before construction development. For the 200-acre site, with a runoff coefficient of 0.2, the outflow would be 566 l/sec (20 ft^3/sec). Various methods are available for computing the required storage based on an outflow of 566 l/sec (20 ft^3/sec).

An estimate of the volume of settled material to be expected can be obtained from information provided in a study for APWA by the firm of Beak Consultants, Ltd.[5] Among figures quoted for suspended solids in stormwater, these settleable solids vary from 0 to 7,640 mg/l, with an average of 687 mg/l. The concentration of solids can vary widely and is depending upon the character and the use of the land from which the storm flow is generated. Using an average value of 700 mg/l, an estimate of the settleable solids per storm is:

$$V = 8{,}420\ \text{m}^3 \times 1{,}000\,\frac{\text{l}}{\text{m}^3} \times 700\,\frac{\text{mg}}{\text{l}}$$

$$\times\ \frac{\text{kg}}{1{,}000{,}000} \times \frac{\text{m}^3}{1{,}600\ \text{kg}} = 3.68\ \text{m}^3\ (130\ \text{ft}^3)$$

On an annual basis the volume of settleable solids is:

$$V = 314{,}000\ \text{m}^3 \times 1{,}000\,\frac{\text{l}}{\text{m}^3} \times 700\,\frac{\text{mg}}{\text{l}}$$

$$\times\ \frac{\text{kg}}{1{,}000{,}000\ \text{g}} \times \frac{\text{m}^3}{1{,}600\ \text{kg}}$$

$$= 137\ \text{m}^3\ (4{,}841\ \text{ft}^3)$$

Assume that 100 percent of all settleable solids will be retained in the ponds.

Temporary Facility at Construction Site

Another application of the swirl separator is as a temporary facility for erosion control at a construction site. For this purpose the foul sewer underflow, conveying most of the settleable solids, would discharge into a soil collector pond and the overflow would discharge into a drainage ditch or channel or flow directly into a watercourse. For this purpose, the conventional cattle watering tank, with a diameter of 3.65 m (12 ft) and height of 0.91 m (3.0 ft), could be used after modification to meet the design details shown in Figure 12. Figure 14, Standard Stock Watering Tank, shows a typical unit.

The riser pipe, shown in Figure 12 as 0.67 m (2.2 ft), could be changed to 0.61 m (2.0 ft) to utilize standard size pipe. The clarified overflow outlet could be attached directly to the underside of the chamber and could be made rectangular in shape. Dimensions of 0.61 m (2.0 ft) wide and 0.22 m (0.75 ft) high would provide a waterway having an area equivalent to the riser pipe. The underflow or foul outlet could likewise be made in rectangular or square shape, attached to the bottom of the box. The outlet should probably be at least 0.15 cm (0.06 in) square to prevent problems with clogging. The outlet could terminate at the outside wall of the chamber, with a 0.15 cm (0.06 in) standard pipe flange for attaching the pipe to convey flow to the soil collection pond.

Assume the following conditions:

Site area tributary to chamber is 3.12 ha (8 ac)

Runoff coefficient C is 0.4

Time of concentration is 15 min

Rainfall intensity is 6.35 cm/hr (2.5 in/hr)

For

$Q = C\,i\,A$:

$= 0.4 \times 6.35$ cm/hr $\times 3.12$ ha

$= 8$ cm-ha/hr

$= 8 \times 27.8 = 222.4$ l/sec

$Q = 0.4 \times 2.5$ in/hr $\times 8.0$ ac

$= 8\ \text{ft}^3$/sec

From Figures 9, 10, and 11, it is apparent that the largest allowable flow through one chamber is 222.4 l/sec (8.0 ft^3/sec). Therefore, under the above assumed conditions the largest site that can be served by one chamber is 3.12 hectares (8.0 ac). The greatest recovery of solids will occur if a 14-percent draw-off (Figure 11) is used rather than 10-percent (Figure 10) or 5-percent (Figure 9).

From Figure 11, the percentage of various size solids to be recovered will be as follows:

Size Solids		Percentage
mm	in	Recovery
0.35	0.014	85
0.30	0.012	73
0.25	0.009	53
0.18	0.007	37
0.16	0.006	31

A 14-percent draw-off means that this percentage of the peak flow will pass through the underflow outlet to the soil collection pond. This amounts to 0.14 x 222.4 l/sec (8 ft^3/sec) = 32 l/sec (1.1 ft^3/sec). The head or depth of water above the underflow outlet will be 0.61 m (2.0 ft) when the outlet weir

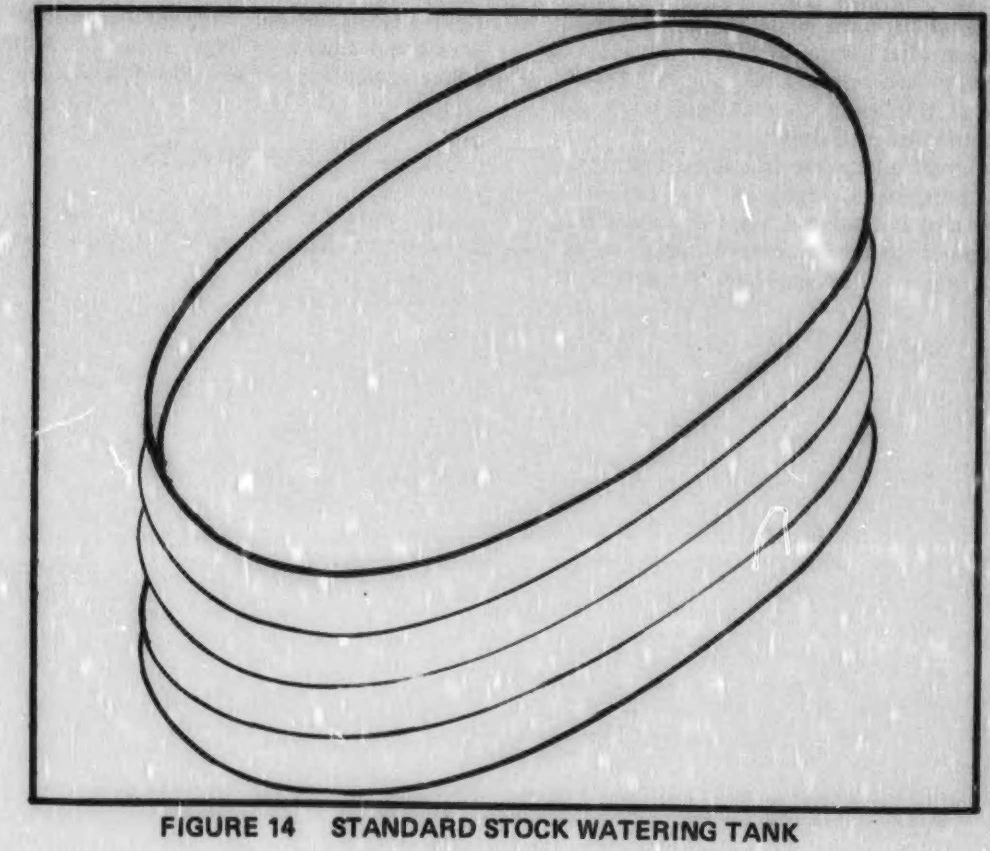


FIGURE 14 STANDARD STOCK WATERING TANK

starts overflowing. At peak flow this head may increase to 0.76 m (2.5 ft). Approximate hydraulic computations indicate that this head is too small to permit use of a 0.10-m (0.33 ft) diameter underflow outlet. If an outlet pipe 0.15 m (0.5 ft) in diameter is used, the head is sufficient to force the flow through about 15 m (50 ft) of outlet.

To meet the recovery performance shown in Figure 11 it is necessary to keep the underflow to about 32 l/sec (1.1 ft^3/sec). To prevent decreasing the rate of underflow due to backwater, the maximum water level in the soil collection pond should be below the top of the underflow pipe. The most practical way of regulating the underflow rate would be to provide a shear gate at the outlet pipe and to determine the actual setting of the gate from measurements of the volume in the collection pond during actual storm conditions.

A further design consideration is the volume of the soil erosion collection pond. Obviously, the foul sewer discharge from the swirl chamber underflow will outlet into the pond, and clear effluent will overflow to the selected drainage ditch or the designated watercourse during a storm period. However, whenever the rate of flow into the swirl chamber is not sufficient to fill the chamber to the overflow weir crest, all of the storm runoff will discharge through the foul sewer into the soil collection pond. Thus, the rate of flow into the pond will vary from 0 to 32 l/sec (1.1 ft^3/sec). Hence, if it is desired to provide storage for all underflow in a 4-hr storm the required storage would be 32 l/sec (1.1 ft^3/sec) x 4 x 60 x 60, or 447 m^3 (15,800 cu ft). This would require a pond 1.2 m (4 ft) deep and 18.9 m (62 ft) square. If a 2-hr detention time is considered adequate to settle out the suspended solids, then the depth could be reduced to 0.61 m (2 ft) or the surface dimensions of the pond reduced. An overflow weir should be provided to pass 32 l/sec (1.1 ft^3/sec) when the pond becomes filled to the designed depth.

The chief advantage of such a temporary construction swirl separator is that it is portable and has no mechanical parts. Thus, the chamber could be moved about on the construction site, as required, or moved to other sites. Multiple units could be used to meet requirements of larger sites or to remove higher percentages of suspended solids.

REFERENCES

6. *Practices in Detention of Urban Stormwater Runoff.* APWA Special Report No. 43, Table 8, p. 33.

CHAPTER IV
GLOSSARY OF PERTINENT TERMS

Cattle Watering Tank – A standard, commercially available tank or tub used on farms, ranches and stock feeding lots for dispensing drinking water for cattle and other livestock.

Concentric Skirt – A vertical sheet or panel, constructed in circular form concentric with the outer diameter and the overflow downdraft pipe in a swirl chamber for the purpose of separating flow zones and acting as a suppressant of any short-circuiting of flow patterns or the overflow of floating solids with the effluent.

Depth of Chamber – The vertical distance between the bottom of the swirl chamber and the crest or lip of the overflow weir, or the level of the flat weir disc; the depth of the chamber to the overflow level.

Erosion – The washing or scouring action of stormwater on the land, resulting in the displacement and movement of grit, silt and other indigenous solids with the wastewater flow; the type of solids which are intended to be removed from the flow by the swirl concentrator chamber.

Flat Weir Disk – The flat circular plate that extends around the overflow pipe in the swirl chamber, to a predetermined diameter, over which the clarified effluent flows on its way to the overflow opening.

Flow Spoiler – Vertical energy dissipating baffle or plate installed on the weir disc or elsewhere in the swirl concentrator chamber for the purpose of preventing excessive flow disturbances and dampening the development of free vortex flow patterns and other undesired flow conditions in the chamber.

Foul Sewer – A sewer line, from the bottom of the swirl concentrator chamber to some point of discharge to an interceptor sewer, a catchment basin or other point of solids disposal, installed for the purpose of drawing off the solids slurry retained in the swirl chamber due to the recovery efficiency of the device.

Gilsonite® – A test material used in the swirl studies to simulate the grit material that will be contained in erosion runoff flows into prototype units in the field; solids having a specific gravity of 1.06 and a size range of 0.5 to 3 mm.

Grit – Solids carried by erosion runoff waters which, because of their size, $>$0.2 mm (0.008 in), and specific gravity, 2.65, settle readily in a swirl concentrator chamber.

Inlet Baffle – A structural plate installed from the inlet to the overflow weir for the purpose of producing or inducing the desired flow pattern in a swirl chamber; a device to serve as a guide for the incoming flow and to place it in circulatory action to take full advantage of the swirl secondary flow pattern in the chamber.

Petrothene® – A synthetic plastic material which, in shredded or dust form, has a specific gravity of 1.01 and was used in the study to simulate the lighter silts and clays which may be contained in erosion runoff wastewater to be treated by prototype field units.

Prototype – A full-scale version of the laboratory test model, designed to handle erosion runoff in actual practice; in this study, a scaled-up replica of the laboratory model of a size that would be four times larger than the model itself; in this study, one prototype proposed for actual field use on a temporary basis would be a conventional, commercial cattle or stock watering tank.

Recovery – The percentage of solids introduced into a swirl concentrator chamber that will be retained as settled material in the bottom of the chamber and drawn off through the foul sewer; solids carried over with the clarified effluent are not considered as part of the recovery in the current studies.

Swirl Concentrator Chamber – A cylindrical tank or chamber, in which the shape, method of inflow and overflow, and internal appurtenant structures induce a swirl-type flow pattern which produces the desired separation of solids from the liquid flow.

Underflow – The slurry, containing the recovered solids, which is withdrawn from the bottom of the swirl concentrator chamber; the converse of the clarified overflow; the erosion solids which the prototype swirl chamber is intended to recover and, thus, prevent from causing environmental pollution, loss of soil cover, and downstream siltation.

CHAPTER V
APPENDIX
(LaSalle Hydraulic Laboratory Report)

Previous research has been carried out on the Swirl Concentrator, covering its application as a stormwater regulator, a grit separation device, and a primary settling chamber. The present study was undertaken to investigate the application of the swirl solids separation principle to the treatment of erosion runoff. The same model used in previous studies was utilized, with modifications that would accommodate larger flows and demonstrate the capabilities of a prototype device that would be simple, sturdy, moveable, and easy to operate.

Since the object of the study was to develop a design that would remove grit particles whose size and gradation would depend on the nature of the watershed area and its indigenous soils, three kinds of solid materials were used in the model to allow interpretation and interpolation of results. Scaling up was accomplished to provide recovery rates for various sizes of prototype particles as a function of discharge rates.

The principle in the swirl separation of erosion soil solids from runoff waters covered a controlled combination of solids settling with rotational liquid velocity, induced by means of spill over an overflow weir, the slope of the chamber floor and a bottom foul draw-off. Modifications were innovated and investigated in order to obtain optimum removal of the solids. The foul outlet was provided during construction of the model and a continuous underflow was drawn off during all tests at predetermined rates.

The basic layout was evolved from the laboratory's previous experience with the swirl combined sewer overflow regulator configuration and based on the desire to use standard cattle watering tanks in actual field installations. These commercial tanks are 3.66 m (12 ft) diameter and 0.91 m (3 ft) deep; they would provide the basic shell of an economical swirl chamber. The inlet, circular weir, clear effluent overflow, and foul outlet could be added at moderate cost.

Description of the Model

The central part of the hydraulic test model was the separation chamber, which took the form of a vertical Plexiglas cylinder with 1:15 cement floor slope in the first stage of the tests, as shown on Figure 3 and Figure 4, contained in Chapter II of this report. The floor slope was later eliminated and the chamber floor was made flat, level with the inlet floor elevation. A spiral flow guide encircling the foul outlet was embedded in the floor for some tests of the research series.

In the center of the cylinder an embedded polyvinyl chloride (PVC) pipe, 15.2 cm (6 in) inside diameter, provided the support for the circular weir and the outlet which discharges the clear effluent overflow spilling over the weir. The elevation of the weir was maintained constant at 15.2 cm (6 in) above the inlet floor level during the entire series of tests.

Inflow to the chamber was supplied through PVC pipe, 15.2-cm (6 in) diameter set at a slope of 1:1,000. A vibrating solids injection system was placed in this supply line, 2.14 m (9 ft) upstream of the chamber. Water supply for the model was obtained through a pipe directly connected to the constant level tank in one of the laboratory's permanent pumping stations.

The overflow effluent through the central outlet pipe was conducted to a large settling basin equipped with a calibrated V-notch weir. A point gauge in a manometer pot was used to read the level in the basin, determining the discharge going over the V-notch weir.

A flexible 2.5 cm- (1 in) diameter tygon tube was placed inside the cylinder beneath the floor of the test chamber to collect the foul flow. The foul flow was withdrawn from the bottom of the cylinder, and conducted to a solids settling tower fitted with an adjustable level outlet pipe which could be raised or lowered at will to control the rate of discharge drawn off through the foul outlet.

The suggested use of a conventional cattle watering tank as the prototype swirl chamber established the model scale of 1:4. This meant that the prototype unit would have to be operating with a 61 cm (24 in) square duct entering a 3.66-m (12 ft) diameter chamber, based on the first step of the study. Later, the square duct inlet was reduced to 0.40 cm (0.16 in) while the chamber remained unchanged.

The selected discharges (Q_m) to be tested were respectively, 3, 5, and 7 l/sec (0.8, 1.3, and 1.8 gal/sec) in the model. When transposed at the prototype scale (Q_p), these values represented the following flows:

Q_m	l/sec	3	5	7
Q_p	l/sec	96	160	224
Q_p	m^3/sec	0.1	0.16	0.2
Q_p	ft^3/sec	3.4	5.6	7.9
Q_p	mgd	2.2	3.6	5.1

The 3.66 m (12 ft) prototype size chamber, with the weir crest or lip 61 cm (24 in) above the horizontal floor and a central overflow pipe of 67.3 cm (26.5 in) diameter, would give, respectively, the following detention times:

Q_m	l/sec	3	5	7
	(ft^3/sec)	(0.1)	(0.2)	(0.2)
Q_p	l/sec	96	160	224
	(ft^3/sec)	(3.4)	(5.6)	(7.9)
Detention	(sec)			
Prototype		54.2	32.5	23.2

Grit Simulation in the Model

The amount and composition of the erosion runoff depends essentially on topography and the nature of the soil of the watershed area. The nature of the soil particles which are to be removed from the runoff flow in a proposed prototype structure is not precisely known.

According to their grain sizes, soil particles are classified as sand, silt, and clay. Following is a list of the generally accepted soil classifications, according to grain size:

Coarse Sand	4.8-2.0 mm	(0.19 - 0.08 in)
Medium Sand	2.0-0.4 mm	(0.08 - 0.02 in)
Fine	0.4-0.05 mm	(0.02 - 0.002 in)
Silt	0.05-0.005 mm	(0.002 - 0.0002 in)
Clay	Smaller than 0.005 mm	(0.0002 in)
Colloidal clay	Smaller than 0.001 mm or μ	(0.00004 in)

To ascertain the range of simulation used in the model, the approach involved determination of the kind of solids which could be represented by the materials commonly used in the laboratory for such solids simulation.

Gilsonite – SG 1.06

0.5 mm (0.02 in) > d > 3 mm (0.12 in)

The Gilsonite used in these tests had a gradation curve as shown in Figure 15, Gradation Curve for Gilsonite Used in Model. Figure 16, Prototype Settling Velocities Simulated by Gilsonite – SG 1.06, shows the settling velocity corresponding to various particle sizes for the model and prototype at scale 1:4, determined according to the approach described by Larras.[7] This work is based on irregularly shaped particles such as were used in the model studies.

A family of curves for different specific gravities was presented in Figure 5. For the range of prototype settling velocities simulated by the Gilsonite in Figure 15, it is possible, in Figure 5, to find the particle sizes for specific gravity 2.65 corresponding to erosion runoff components.

As an example, in Figure 16 the finest Gilsonite particle of 0.5 mm (0.02 in) (No. 35 sieve) simulates, at 1:4 scale, a settling velocity of 1 cm/sec (0.4 in/sec). Using this value in Figure 5, grit solids with specific gravity 2.65 would have a particle size of 0.14 mm (0.0055 in). However, given the relatively large particle sizes represented by the Gilsonite, shredded Petrothene X – SG 1.01 was judged more adequate for testing of further improvements in the swirl chamber structure.

Shredded Petrothene X – SG 1.01

0.5 mm (0.02 in) > d > 3.0 mm (0.12 in)

Gilsonite, at prototype scale 1:4, left a zone of fine grit not represented. Petrothene X, with particle sizes ranging from 0.5 to 3

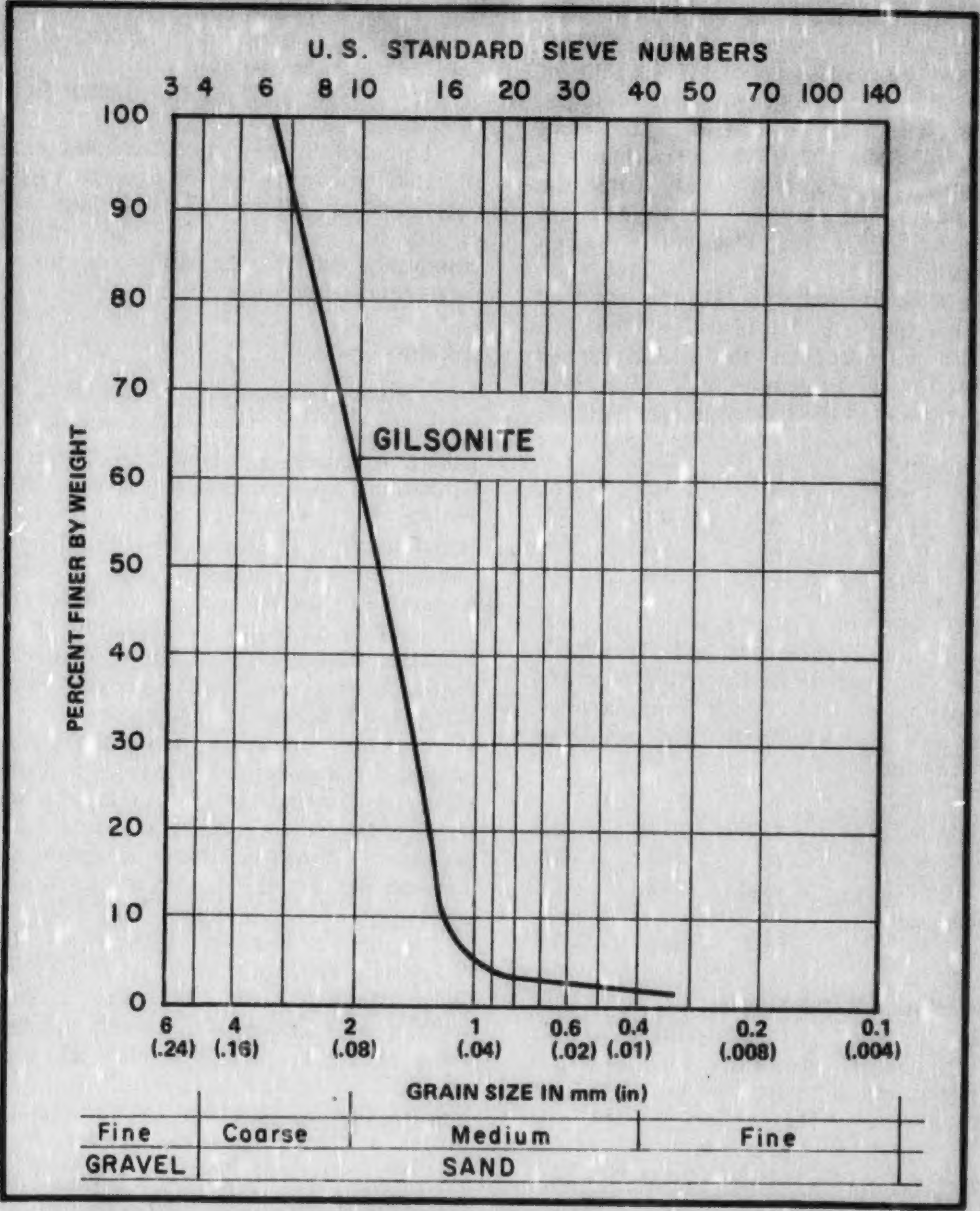


FIGURE 15 GRADATION CURVE FOR GILSONITE USED IN MODEL[1]

---

[1] The Helical Bend Combined Sewer Overflow Regulator, USEPA Report, EPA-600/2-75-062, December 1975, Figure 8, p. 18.

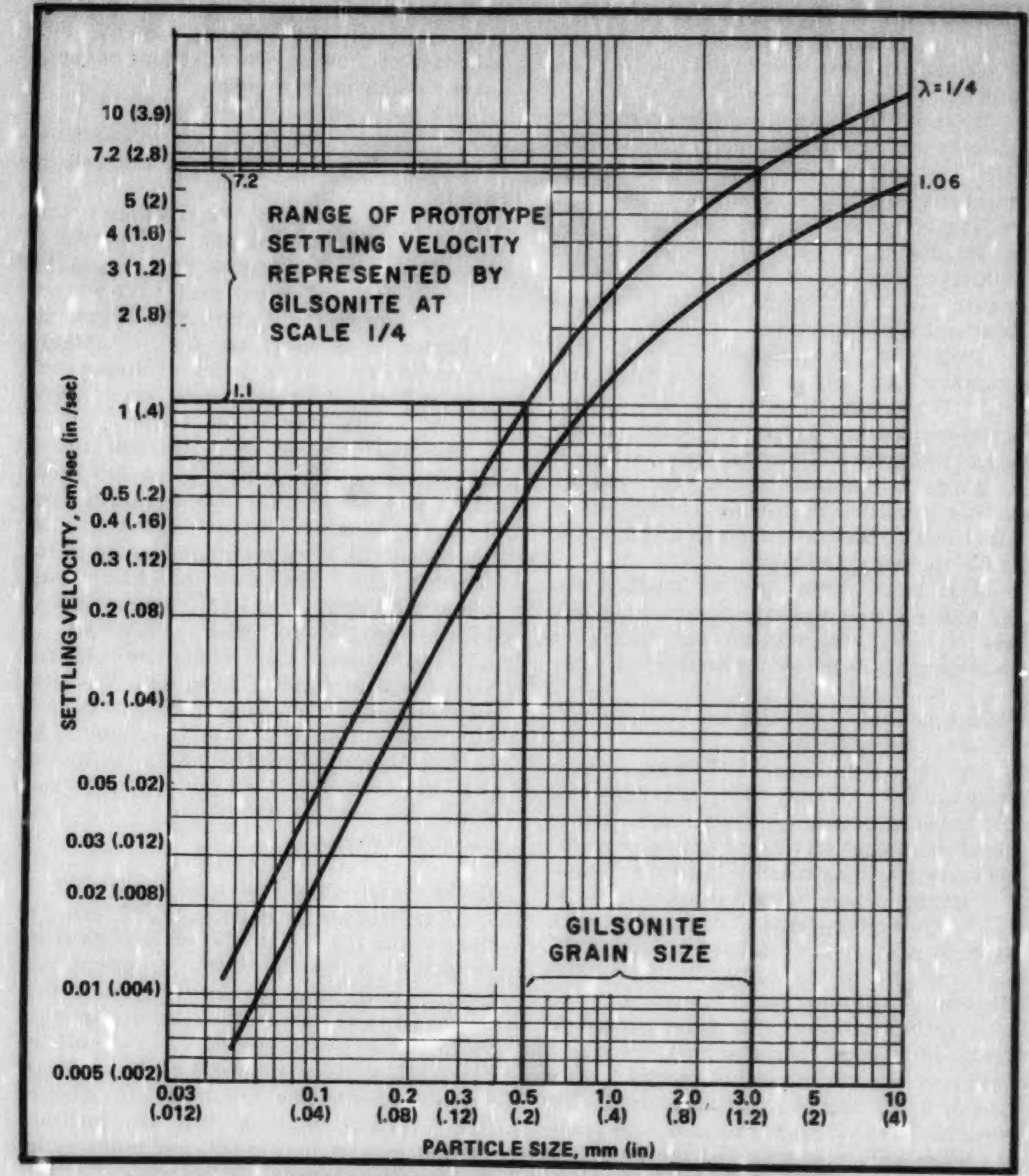


FIGURE 16 PROTOTYPE SETTLING VELOCITIES SIMULATED BY GILSONITE – SG 1.06

mm (0.02 to 0.12 in), was selected to fill this void; its gradation curve is shown in Figure 17, Gradation Curve for Petrothene Used in Model.

The same procedure described earlier for Gilsonite was followed to define the settling velocities of the particles simulated by Petrothene X at scale 1:4 as shown in Figure 18, Prototype Settling Velocities Simulated by Petrothene – SG 1.01. Similarly, the prototype particle sizes can be found in Figure 19, Prototype Particle Sizes Represented by Petrothene.

Following an example through this procedure again, the finest particle in the model, 0.5 mm (0.02 in) at scale 1:4, gives a prototype settling velocity of 0.2 cm/sec (0.4 in/sec) in Figure 7. Using this value in Figure 8, it can be determined that the smallest particle simulated at specific gravity 2.65 is 0.052 mm (0.004 in), or down to the lower end of the fine sand range.

Due to its relative ease of handling and the wide range of recovery rates it simulated, this material was selected for testing of improvements in the swirl chamber structure.

Petrothene Dust – SG 1.01
d < 1.0 mm (0.04 in)

As shown in Figure 8, Petrothene with grain size 0.5 – 3.0 mm (0.02 – 0.12 in) does not cover the prototype silt range. It was therefore evident that a new kind of material with lower settling velocity had to be found.

Settling column tests performed by T. W. Beak Consultants, in connection with previous swirl studies,[2] defined the size of the dust particles in the range of 120 to 500 microns. Use of these values in Figures 18 and 19, and utilizing the same procedure described earlier, indicates that the finest prototype size represented at specific gravity 2.65 is 0.012 mm (12 microns), covering 95 percent of the silt range (50 to 0.5 microns).

Since only one scale for the prototype was being considered (λ = 1:4), all results could be presented more simply as shown in Figure 20, Range of Prototype Grit Particle Sizes (SG 2.65) Simulated, Respectively, by Gilsonite, Petrothene, and Petrothene Dust. The figure shows directly the prototype particle sizes at specific gravity 2.65 (ordinate) as a function of the model particle sizes (abscissa). This figure also has the advantage of showing either overlaps or gaps, if any, existing in the simulation.

Settling Velocity Distributions for Gilsonite, Petrothene, Petrothene Dust, and Stormwater Runoff

Settling velocity distribution for Petrothene dust, carried out by T.W. Beak Consultants, is represented in Figure 21, Settling Velocity Distributions for Petrothene Dust and Stormwater Runoff. Also delineated in Figure 21 is the curve for the settling velocity distribution of solids in stormwater runoff. Both of these curves were taken directly from the Beak report.

Above the model curve for Petrothene dust in Figure 21, a second curve has been drawn, giving the settling velocity distribution at prototype scale 1:4 represented by the model material, when transposed according to Froude's Law. The same procedure was followed for Petrothene [0.5 – 3 mm (0.02 – 0.12 in)] and Gilsonite [0.5 – 3 mm (0.02 – 0.12 in)] and the results are plotted respectively in Figure 22, Settling Velocity Distributions for Shredded Petrothene X and Stormwater Runoff, and in Figure 23, Settling Velocity Distributions for Gilsonite and Stormwater Runoff. The extrapolated stormwater runoff curve from Beak was also traced in the figure.

Model Simulation of Prototype Runoff

Examination of Figures 21, 22, and 23 shows clearly that the model particle simulation is several orders of magnitude away from the settling velocities given in the Beak Consultants, Ltd., runoff sample. Further analysis of the curve for runoff in Figure 21, shows it to have a median settling velocity considerably less than 0.01 cm/sec (0.004 in/sec), meaning that the particles were at least as fine as silt, and probably in the clay sizes range.

Samples like these fall into the class of colloidal turbid water which might require at least days of quiescent settling to be clarified. It is evident, therefore, that there should be no pretention of trying to remove these fine particles in the swirl concentrator.

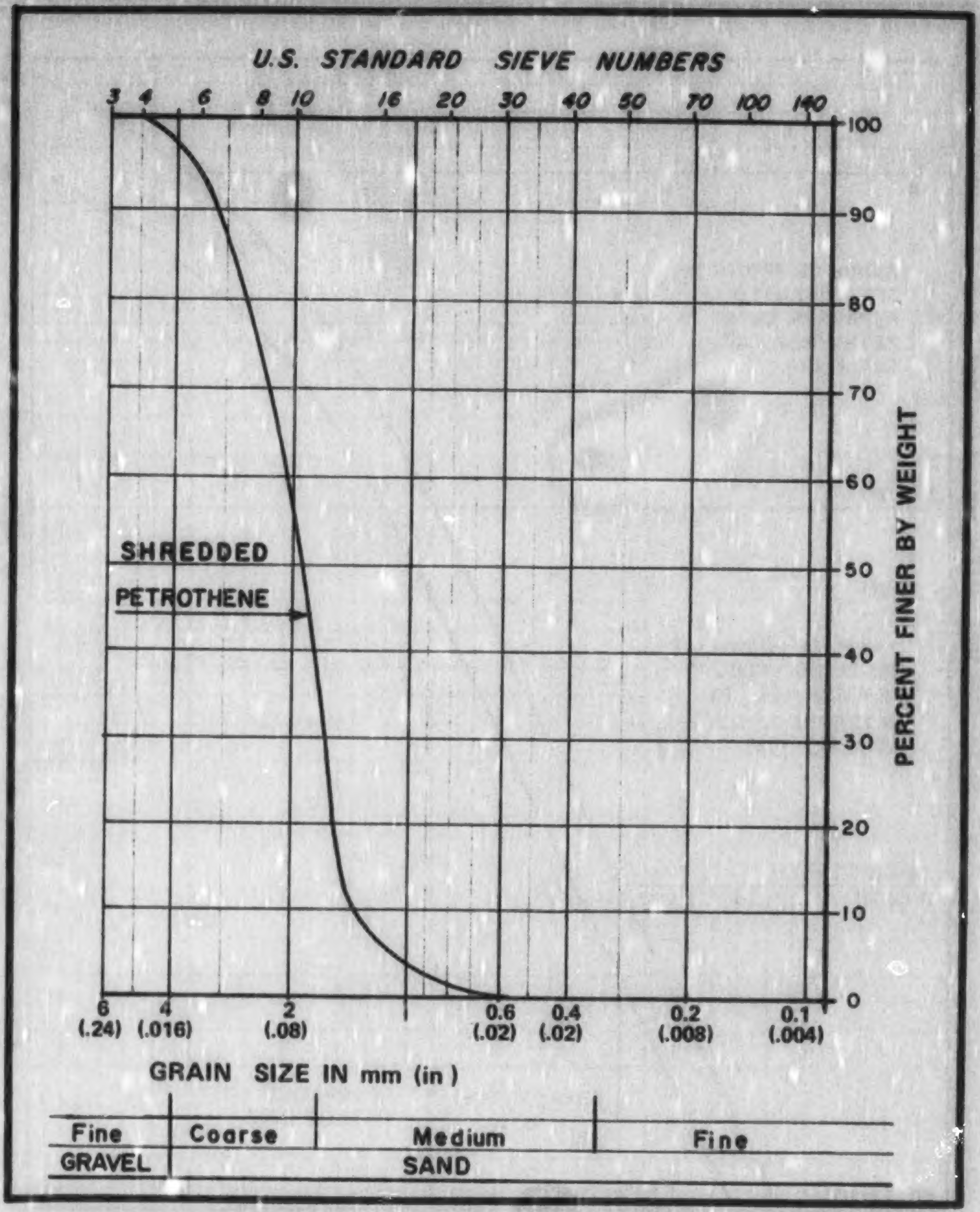


FIGURE 17 GRADATION CURVE FOR PETROTHENE USED IN MODEL

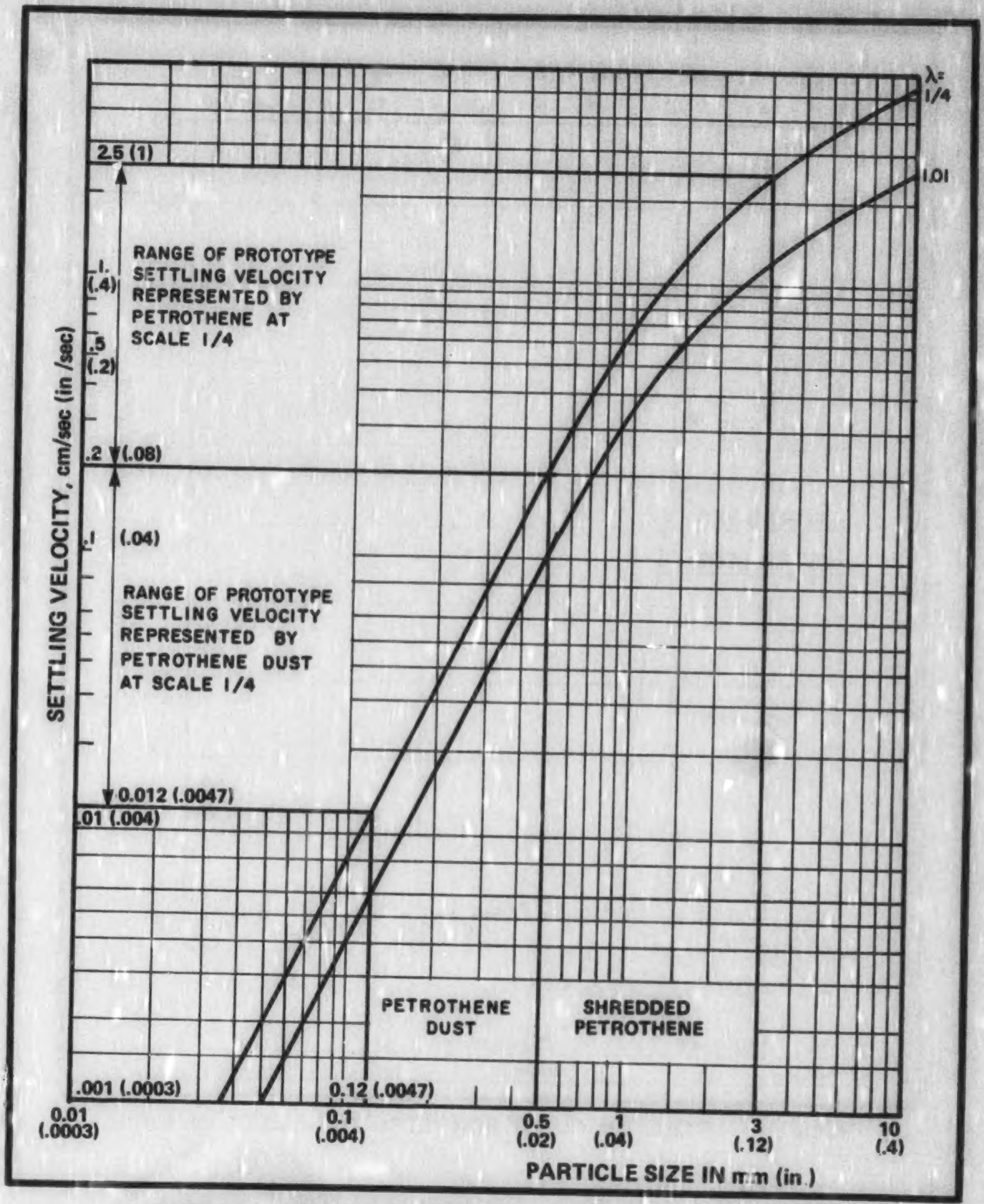


FIGURE 18 PROTOTYPE SETTLING VELOCITIES SIMULATED BY PETROTHENE – SG 1.01

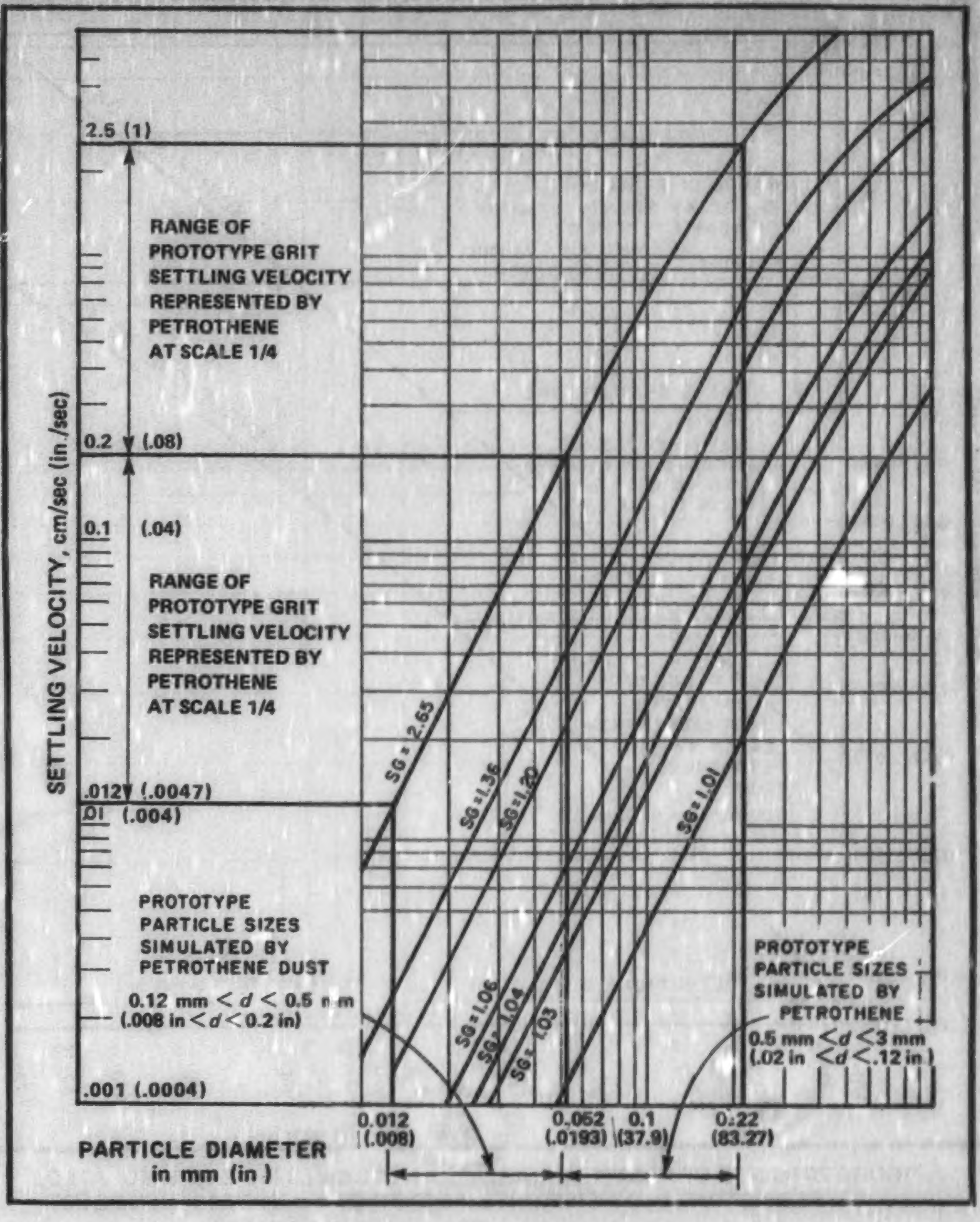


FIGURE 19 PROTOTYPE PARTICLE SIZES REPRESENTED BY PETROTHENE – SG 1.01

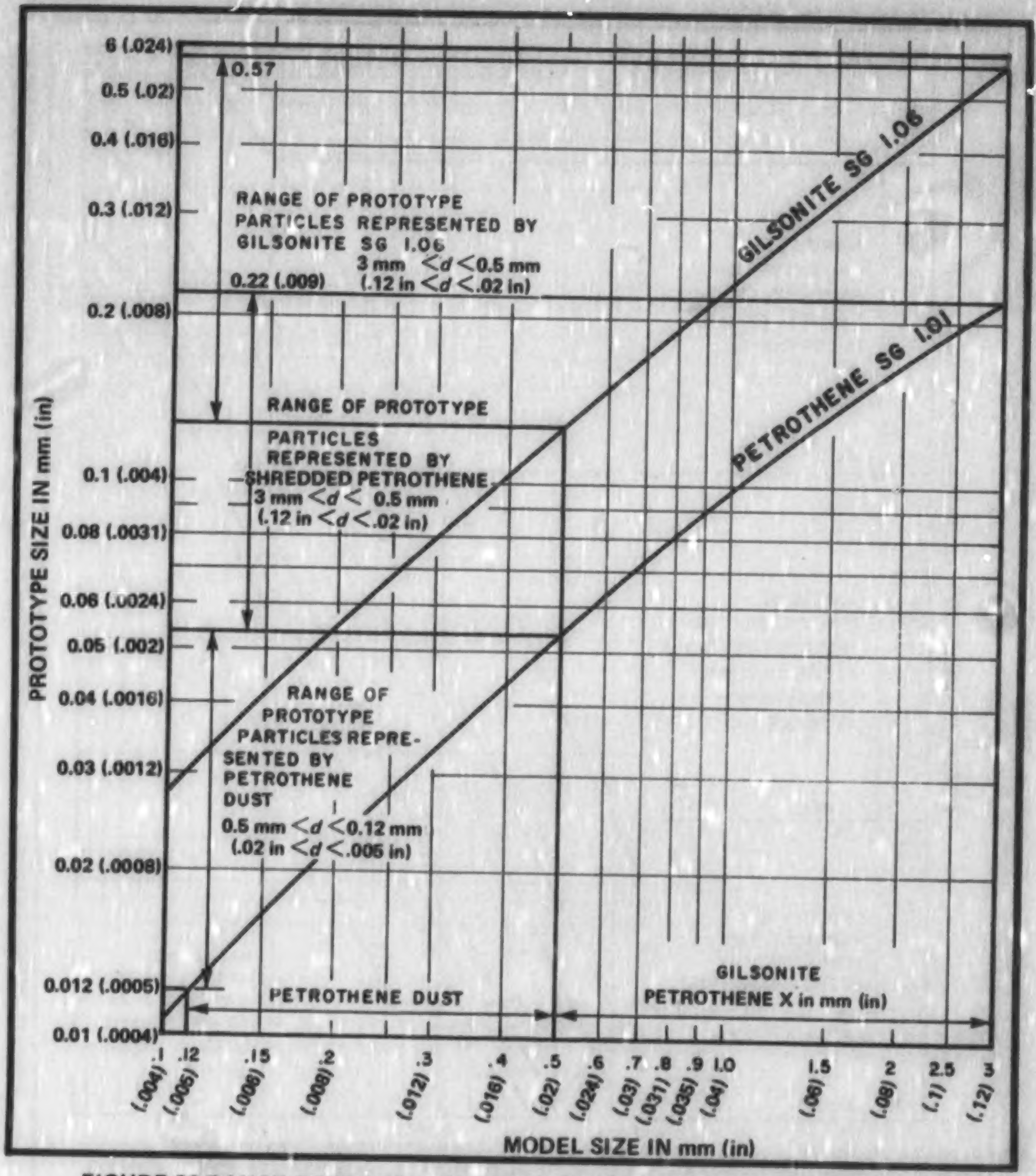
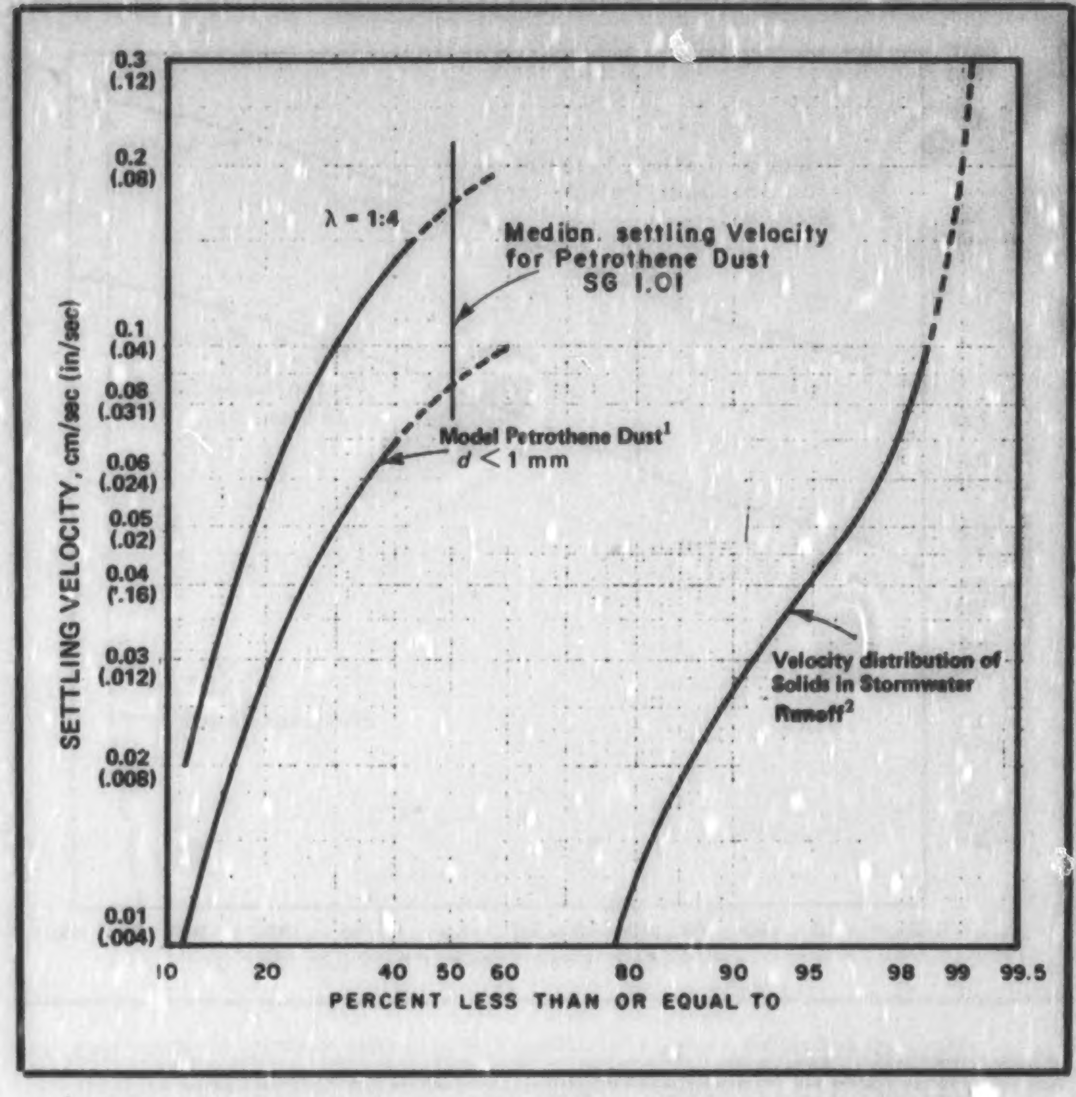


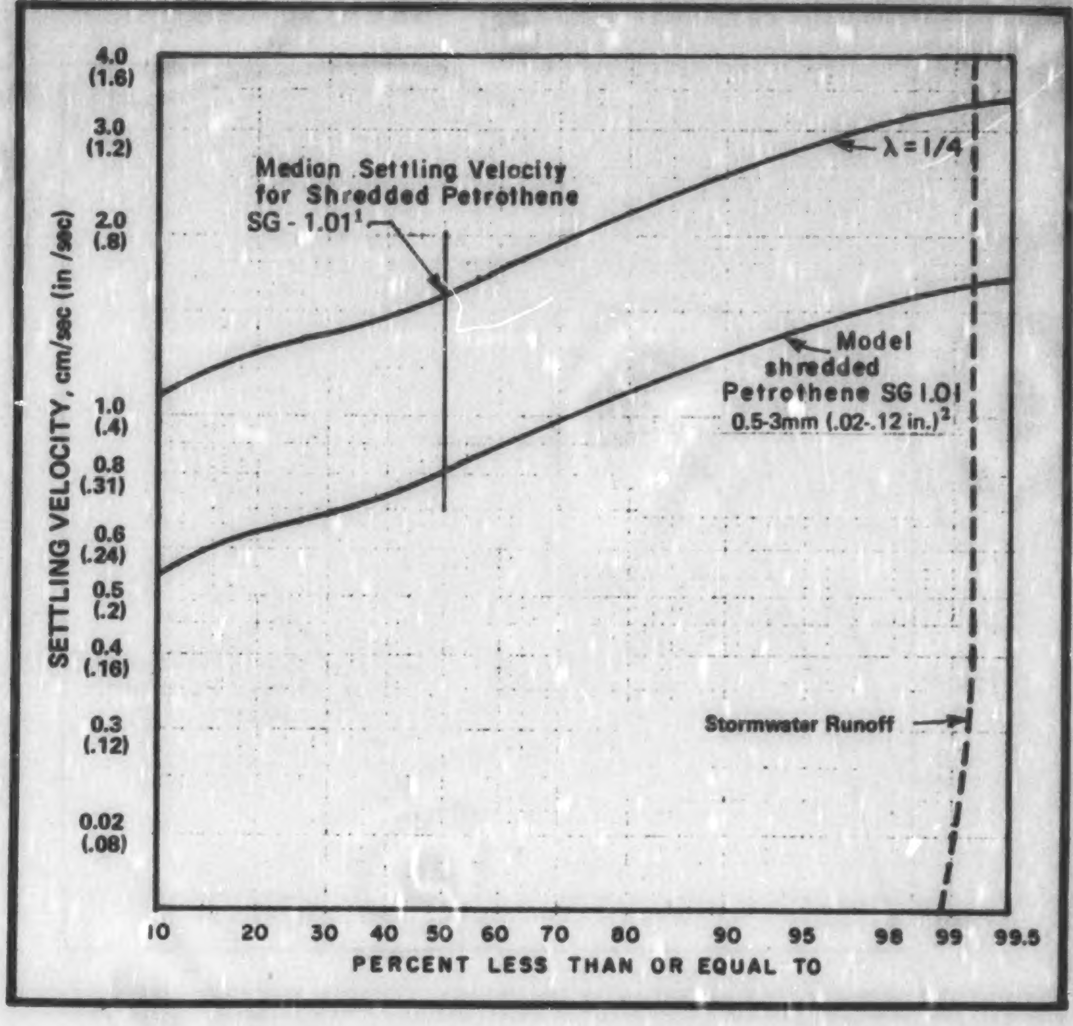
FIGURE 20 RANGE OF PROTOTYPE GRIT PARTICLE SIZES (SG 2.65) SIMULATED, RESPECTIVELY, BY GILSONITE, PETROTHENE and PETROTHENE DUST



[1] Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater. USEPA Report, EPA-670/2-75-011 April 1975 – Figure 12, p. 21

[2] Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater. USEPA Report, EPA-670/2-75-011 April 1975 – Figure 3, p. 9

FIGURE 21 SETTLING VELOCITY DISTRIBUTIONS FOR PETROTHENE DUST AND STORMWATER RUNOFF



[1] Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater, EPA 670/2-75-011 April 1975 – Figure 7, p. 16

[2] Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewater, EPA 670/2-75-011 April 1975 – Figure 3, p. 9

FIGURE 22 SETTLING VELOCITY DISTRIBUTIONS FOR SHREDDED PETROTHENE X® AND STORMWATER RUNOFF

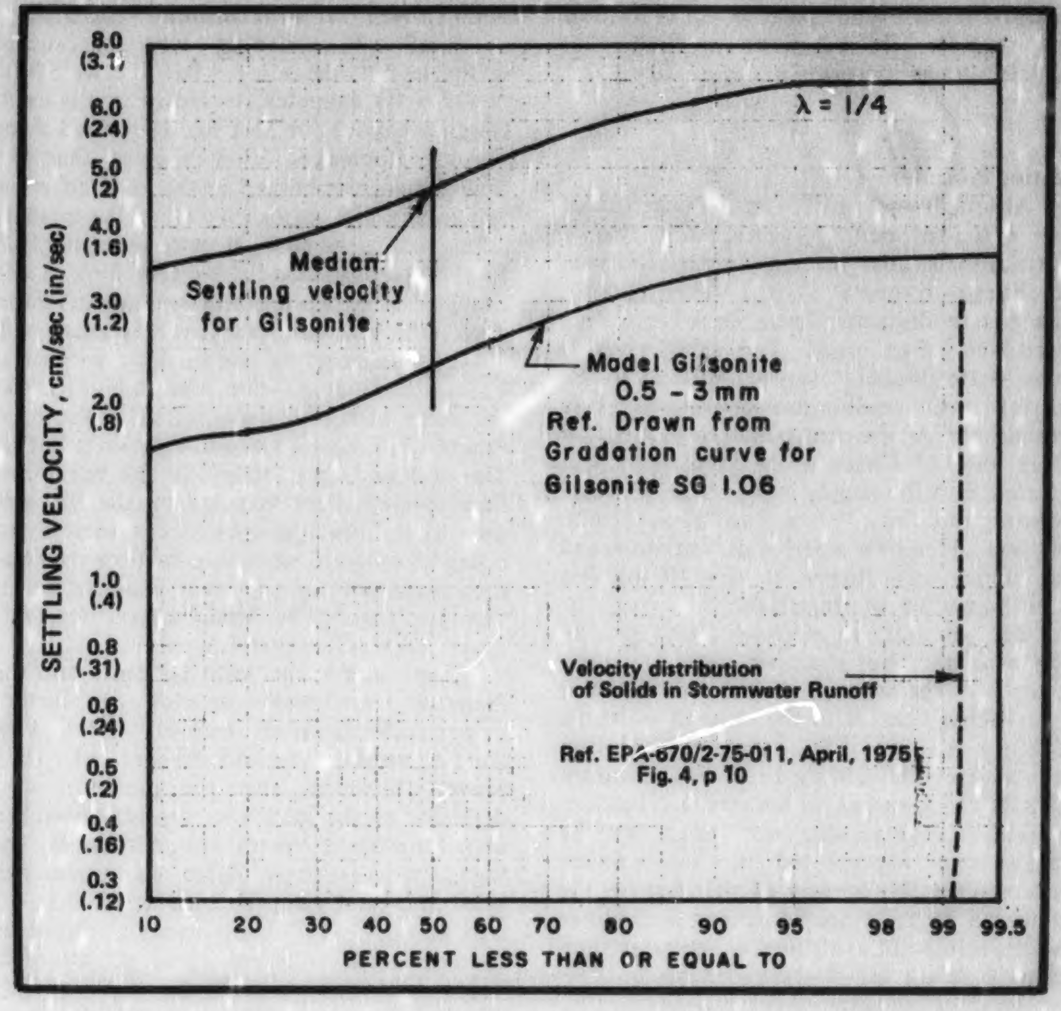


FIGURE 23 SETTLING VELOCITY DISTRIBUTIONS FOR GILSONITE® AND STORMWATER RUNOFF

Model-to-prototype particle transposition will, therefore, be based on the individual particle sizes as portrayed in Figure 20.

Testing Procedure

Although use of the swirl concentrator for erosion runoff clarification would normally involve a continuously varying discharge over a storm hydrograph, steady-state discharges were used for testing purposes. For each individual test a steady-state discharge was set running in the model until equilibrium conditions were established. A mixture containing one liter (0.26 gal) of Gilsonite or Petrothene was injected into the supply pipe, using the same vibrating rate for all tests. The full liter (0.26 gal) was added over a period of 5 minutes and the model was allowed to run 10 minutes after the end of soils injection.

The amount of material found on the bottom of the chamber was measured separately. The same procedure was followed for material floating in the effluent overflow settling basin. The remaining portion deposited in the settling basin was found by subtraction, assuming no material was lost.

The recovery rate was taken as the percentage represented by the amount measured on the bottom of the chamber, as compared to the total found in the chamber and deposited in the effluent overflow settling basin.

Settleable Solids Recovery Results

In discussing settleable solids for the purpose of this study, reference is made to the recovery rates for Gilsonite and shredded Petrothene X, both with a particle size range of 0.5 mm $< d <$ 3 mm (0.02 in $< d <$ 0.12 in) and Petrothene dust with a size range of 0.12 mm $< d <$ 0.5 mm (0.005 in $< d <$ 0.02 in). As described, Gilsonite and Petrothene, both shredded or dust, were considered as representing grit material over the ranges defined in Figure 19. The different steps followed in the model testing are recorded in Table 3, Modifications Tested in Model and Results.

Tests Carried Out With Gilsonite – SG 1.06

Brief tests carried out with the original model layout, including a flat disc weir 0.50 m (11.6 ft) diameter, as shown in Figure 4, Original Layout for Test No. 1, covered three selected discharges. They showed that the flow pattern established in the swirl chamber was an unstable vortex even when the smallest discharge 3 l/sec (0.8 gal./sec) was used. Due to these special conditions prevailing in the chamber, no solids injection was made; hence, no volumetric measurement was taken.

To eliminate the vortex flow pattern, a baffle extending from the inlet to the periphery of the weir was tested, as shown in Figure 4b, Original Layout With Inlet Baffle. This did not completely still the vortex, so flow spoilers were installed on the flat disc weir. These flow spoilers were cut unevenly to obtain a better distribution of flow over the four quadrants of the weir. This format is shown in Figure 24a, Model Layout for Tests 2 to 13 – Modification 1.

Tests carried out with Gilsonite and the deflector were unable to show any further improvements since recovery rates were almost constant around 95 percent. They proved, however, that the presence of a deflector at the inlet end was very useful in increasing the efficiency rate, particularly for high-flow conditions. After the model had been improved using Petrothene X, 0.5 – 3 mm (0.02 – 0.12 in), Gilsonite tests were resumed with different rates of draw-off. Table 3, Modifications Tested in Model and Results, shows quantitative results for those tests. Slight deposits of Petrothene remained in the chamber after the tests, as shown in Figure 25, Deposit of Petrothene Found After 3 l/sec (0.8 gal/sec) Test.

Tests Carried out with Shredded Petrothene X SG 1.01 – 0.5 mm $< d <$ 3 mm (0.02 in $< d <$ 0.12 in)

Tests 8 to 13, subsequently, carried out under the same model conditions illustrated in Figure 24a, confirmed the efficiency of the inlet baffle. Figure 26, Influence of Inlet Deflector on Recovery Rate, shows the significant recovery rate improvement obtained by adding the baffle portrayed in Figure 24a.

TABLE 3
MODIFICATIONS TESTED IN MODEL AND RESULTS

Mod. No.	Fig. No.	Weir θ cm (in)	Inlet Baffle	Draw-off (Percent)	Percent Recovery vs Discharge Recovery 3 l/sec (0.8 gal/sec)	5 l/sec (1.3 gal/sec)	7 l/sec (1.8 gal/sec)	Fig.
			Flat weir disc; 4 uneven flow spoilers; 1/15 floor slope; 15.2 cm x 15.2 cm (6 in x 6 in) inlet size; material used – Gilsonite 0.5 mm < *d* < 3 mm (.02 in < *d* < .12 in) SG 1.06					
1	13	20	No	5	95	90	76	
1	13	20	Yes	5	96	95	95	
			Flat weir disc; 4 uneven flow spoilers; 1/15 floor slope; 15.2 cm x 15.2 cm (6 in x 6 in) inlet size; material used – shredded Petrothene X 0.5 mm < *d* <3 mm (.02 in < *d* < .12 in) SG 1.01					
1	13	20	No	5	42	17	8	14
1	13	20	Yes	5	86	52	22	14
								21
			Circular weir with lip 5.1 cm (2 in) high; 4 even flow spoilers; 1/15 floor slope; 15.2 cm x 15.2 cm (6 in x 6 in) inlet size; shredded Petrothene X 0.5 mm < *d* < 3 mm (.02 in < *d* < .12 in) SG 1.01; spiral flow guide 2.5 cm (1 in) high encircling foul outlet					
2	15	20	Yes	5	71	43	23	
			Spiral flow guide 0.87 m (2.85 ft) high, open at oul inlet					
3	16	20	Yes	5	76	42	23	
			Spiral flow guide 7.6 cm (3 in) high, open at foul outlet					
4	17	20	Yes	5	79	48	25	
			Circular weir with lip 5.1 cm (2 in) high; 4 even flow spoilers; 1/15 floor slope; shredded Petrothene 0.5 mm < *d* < 3 mm (.02 in < *d* < .12 in) SG 1.01; concentric skirt 60.5 cm (24 in) θ immerse 0.5 m (1.64 in) no spiral flow guide; 15.2 cm x 15.2 cm (6 in x 6 in) inlet size					
5	18	20	Yes	5	65	35	18	
			Circular weir with lip 5.7 cm (2.25 in) high; 4 even low spoilers; flat floor; shredded Petrothene 0.5 mm < *d* < 3 mm (.02 in < *d* < .12 in) SG 1.01; no skirt, no spiral low guide; 15.2 x 15.2 cm (6 in x 6 in) inlet size.					

TABLE 3 (Continued)

Mod. No.	Fig. No.	Weir θ cm(in)	Inlet Baffle	Draw-off (Percent)	Percent Recovery vs Discharge Recovery			
					3 l/sec (0.8 gal/sec)	5 l/sec (1.3 gal/sec)	7 l/sec (1.8 gal/sec)	Fig.
11	23	24	Yes	14	81	54	31	25
11	23	24	Yes	20	84	56		25
Circular weir with lip 5.7 cm (2.25 in) high; 4 even flow spoilers; horizontal floor; 10.2 cm x 10.2 cm (4 in x 4 in) inlet size; shredded Petrothene 0.5 mm $< d <$ 3 mm (.02 in $< d <$ .12 in) SG 1.01; no skirt, no spiral flow guide								
12	26	24	Yes	5	62	36	16	27
Circular weir with lip 5.7 cm (2.25 in) high; 4 even flow spoilers; flat floor; 15.2 cm x 15.2 cm (6 in x 6 in) inlet size; Petrothene 0.5 mm $< d <$ 3 mm (.02 in $< d <$ .12 in) SG 1.01; no skirt, no spiral flow guide								
11	23	24	Yes	5	99.5	89	67	28
11	23	24	Yes	10	99.5	93	75	29
Circular weir with lip 5.7 cm (2.25 in) high; 4 even flow spoilers; flat floor; 15.2 cm x 15.2 cm (6 in x 6 in) inlet; Gilsonite 0.5 mm $< d <$ 3 mm (0.2 in $< d <$ .12 in) SG 1.06; no skirt, no spiral flow guide								
11	23	24	Yes	14	99.5	95	84	30
Circular weir with lip 5.7 cm (2.25 in) high; 4 even flow spoilers; flat floor; 15.2 cm x 15.2 cm (6 in x 6 in) inlet; Petrothene dust 0.12 mm $< d <$ 0.5 mm (.004 in $< d <$ .02 in) SG 1.01; no skirt, no spiral flow guide								
11	23	24	Yes	5	46	25	12	28
11	23	24	Yes	10	52	28.5	14	29
11	23	24	Yes	14	56	33	18	30

1. Influence of Weir Lip and Spiral Flow Guide

The next series of alterations included in Modification 2, shown in Figure 27, Model Layout for Tests 14 to 16, Modification 2, involved:

a. The installation around the weir of a lip 5 cm (2 in) high, and four flow spoilers of equal length. The lip crest level was set at the inlet crown elevation.

   This alteration was necessary because the flow level in the chamber had been observed to be controlled by the cross section of the overflow pipe in the tests with the flat disc.

b. The installation of the bottom of the chamber of an embedded spiral flow guide encircling the foul outlet at its inner end.

   The guide was shaped according to the stream lines that had been traced by the flow on the bottom for the intermediate flow. The top of the guide was set level 2.5 cm (1 in) above the chamber floor at

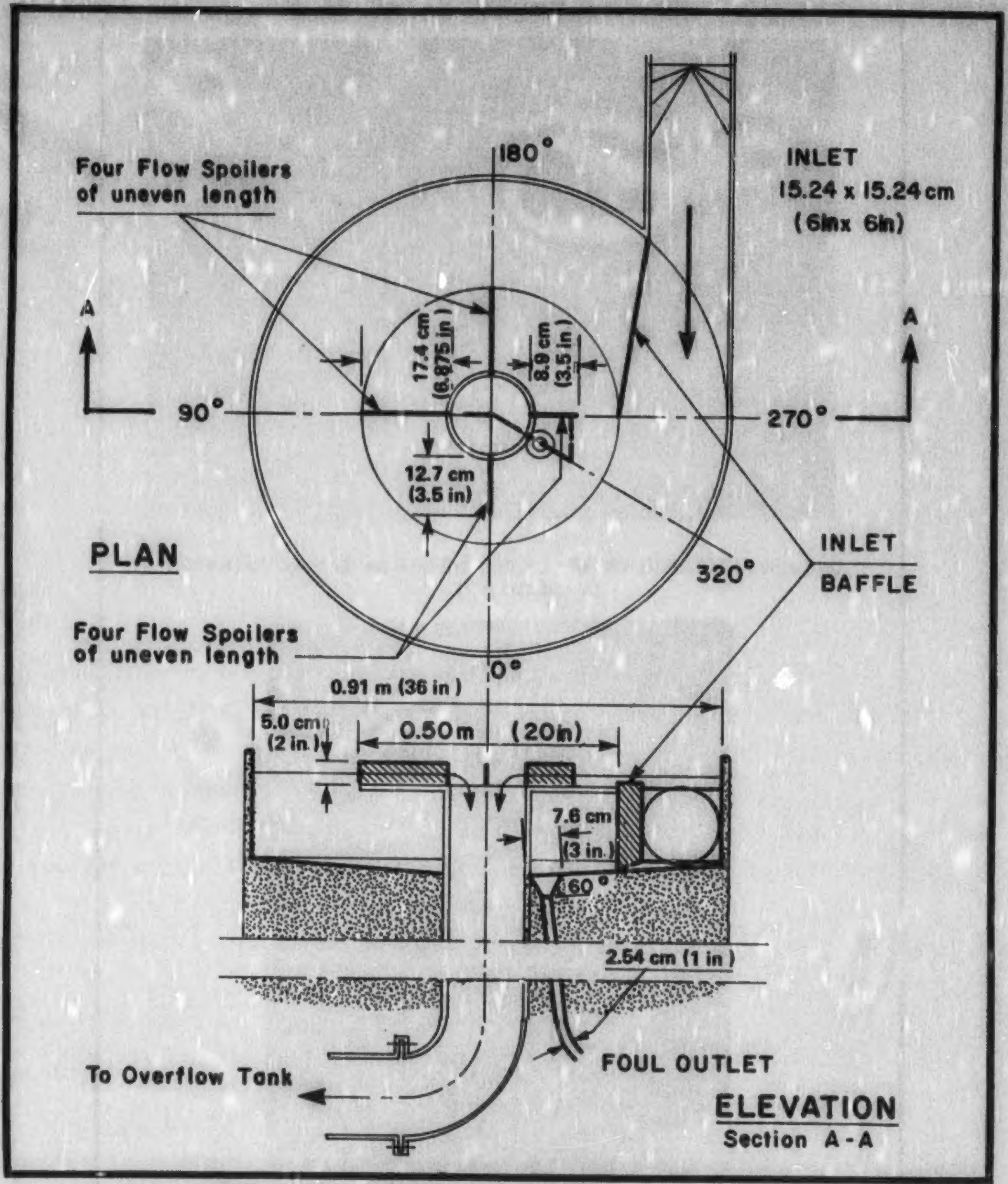
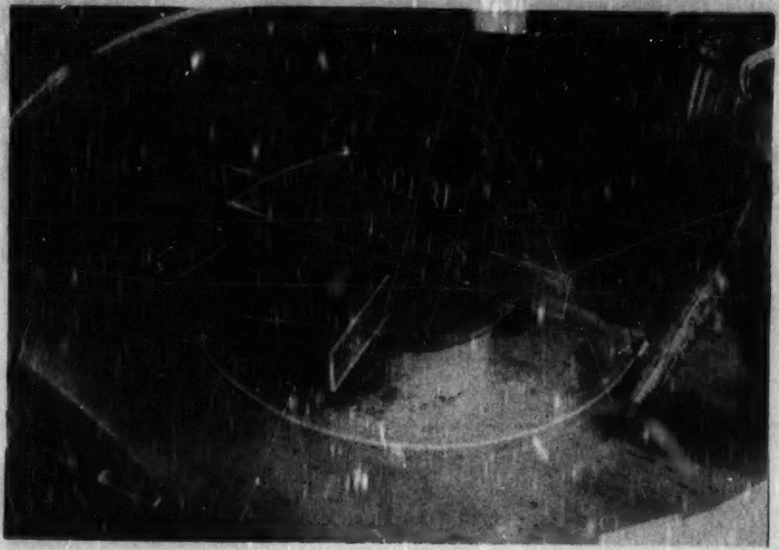
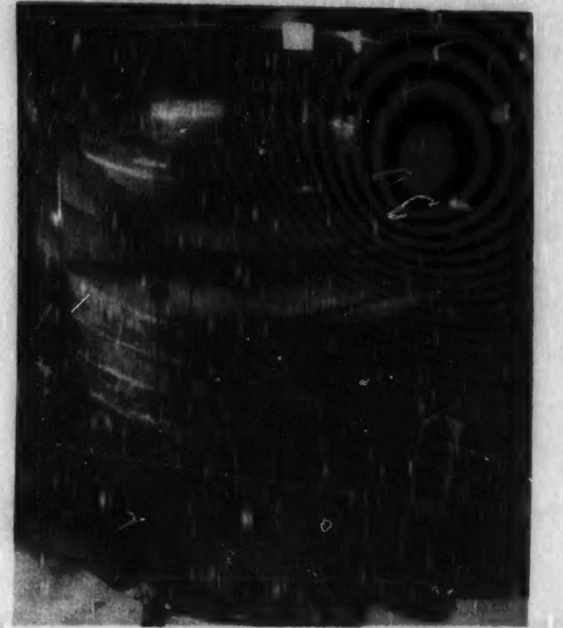

Four Flow Spoilers of uneven length
180°
INLET
15.24 x 15.24 cm
(6in x 6in)
A
A
17.4 cm
(6.875 in)
8.9 cm
(3.5 in)
90°
270°
12.7 cm
(3.5 in)
PLAN
320°
INLET
BAFFLE
Four Flow Spoilers of uneven length
0°
0.91 m (36 in)
5.0 cm
(2 in.)
0.50 m (20in)
7.6 cm
(3 in.)
60°
2.54 cm (1 in)
FOUL OUTLET
To Overflow Tank
ELEVATION
Section A-A

FIGURE 24 a MODEL LAYOUT FOR TESTS 2 to 13
MODIFICATION 1



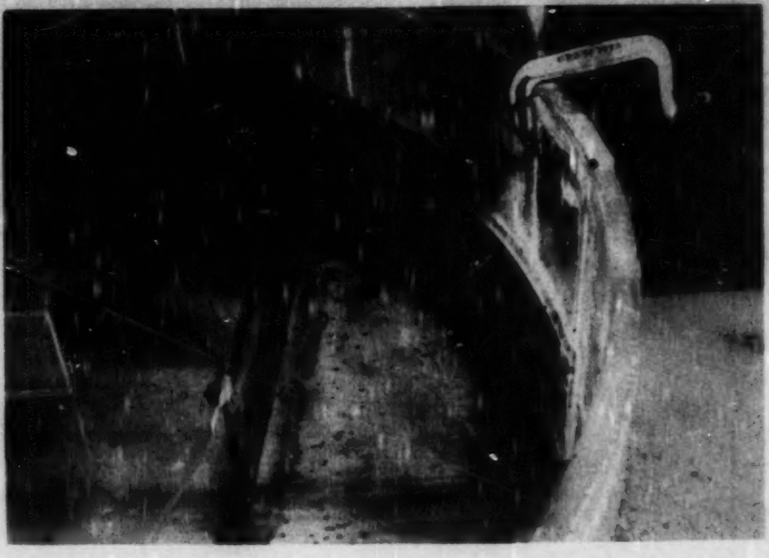
UNEVEN FLOW SPOILERS STUCK ON THE 50.8 cm (20 in) ϕ WEIR DISK
(Modification 1)



MODIFICATION 1 TESTED WITH A 3 l/sec (0.8 gal/sec) DISCHARGE

FIGURE 24 b MODEL LAYOUT FOR TESTS 2 to 13
MODIFICATION 1

DEPOSIT OF PETROTHENE FOUND AT INLET AFTER 3 l/sec (0.8 gps)



DEPOSIT OF PETROTHENE FOUND IN THE CHAMBER BOTTOM AFTER 3 l/sec (0.8 gal/sec) TEST

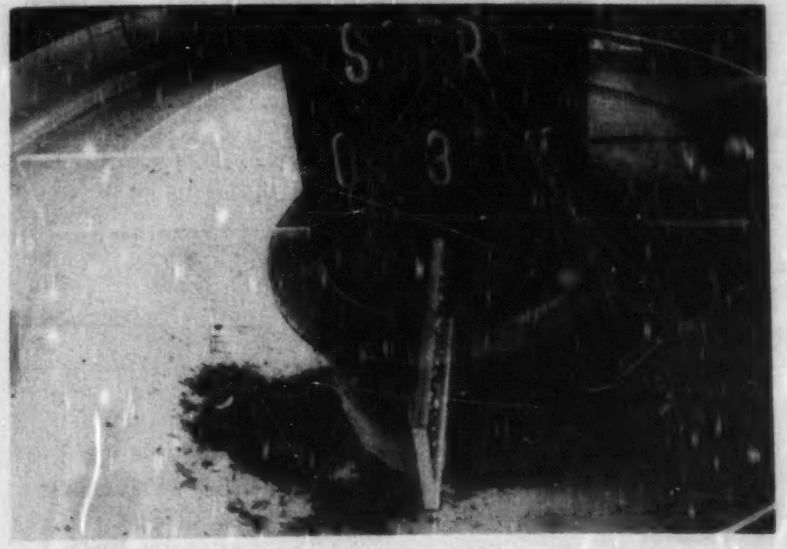


FIGURE 25 DEPOSIT OF PETROTHENE FOUND AFTER 3 l/sec (0.8 gal/sec) TEST

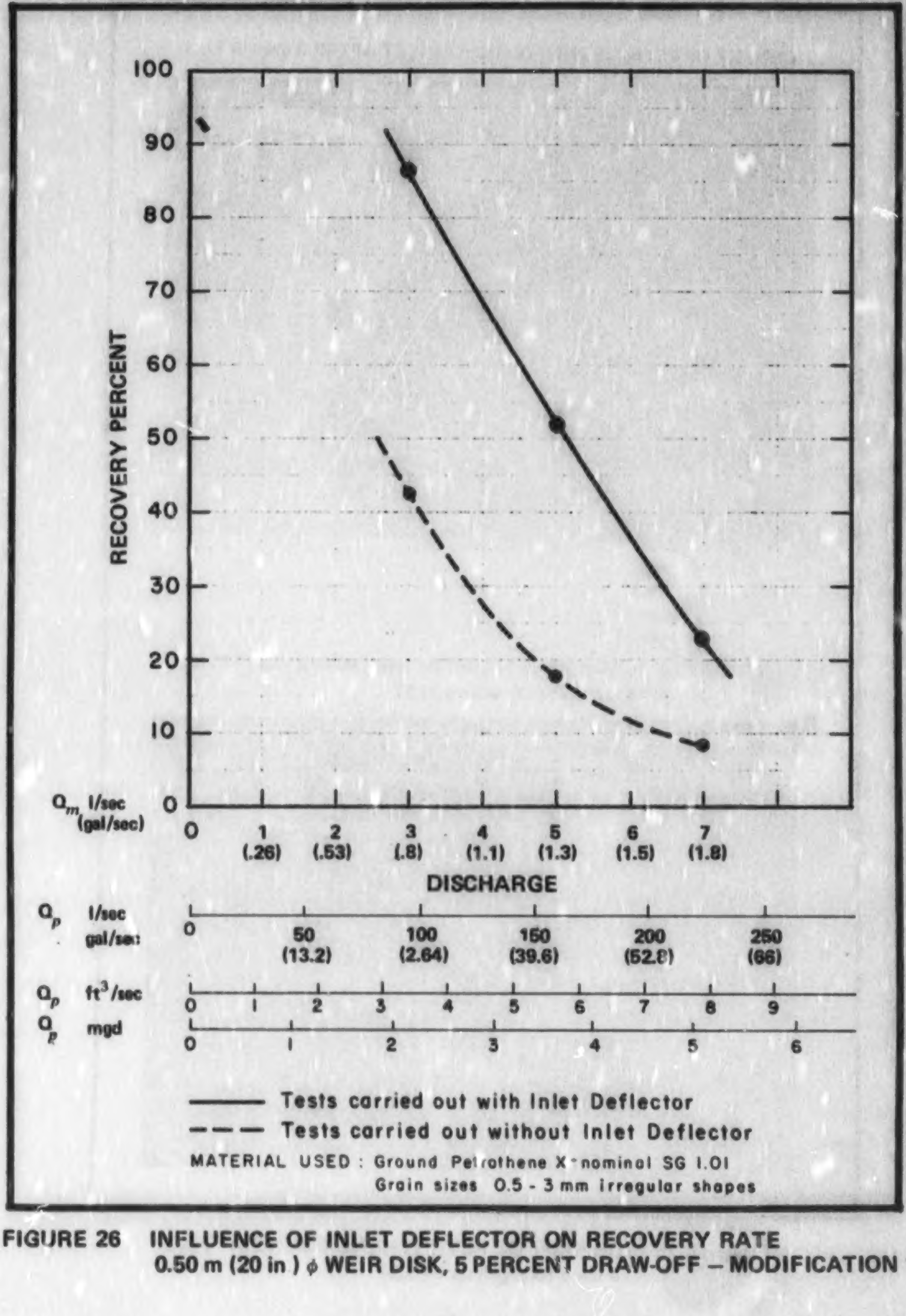


FIGURE 26 INFLUENCE OF INLET DEFLECTOR ON RECOVERY RATE
0.50 m (20 in) ϕ WEIR DISK, 5 PERCENT DRAW-OFF – MODIFICATION 11

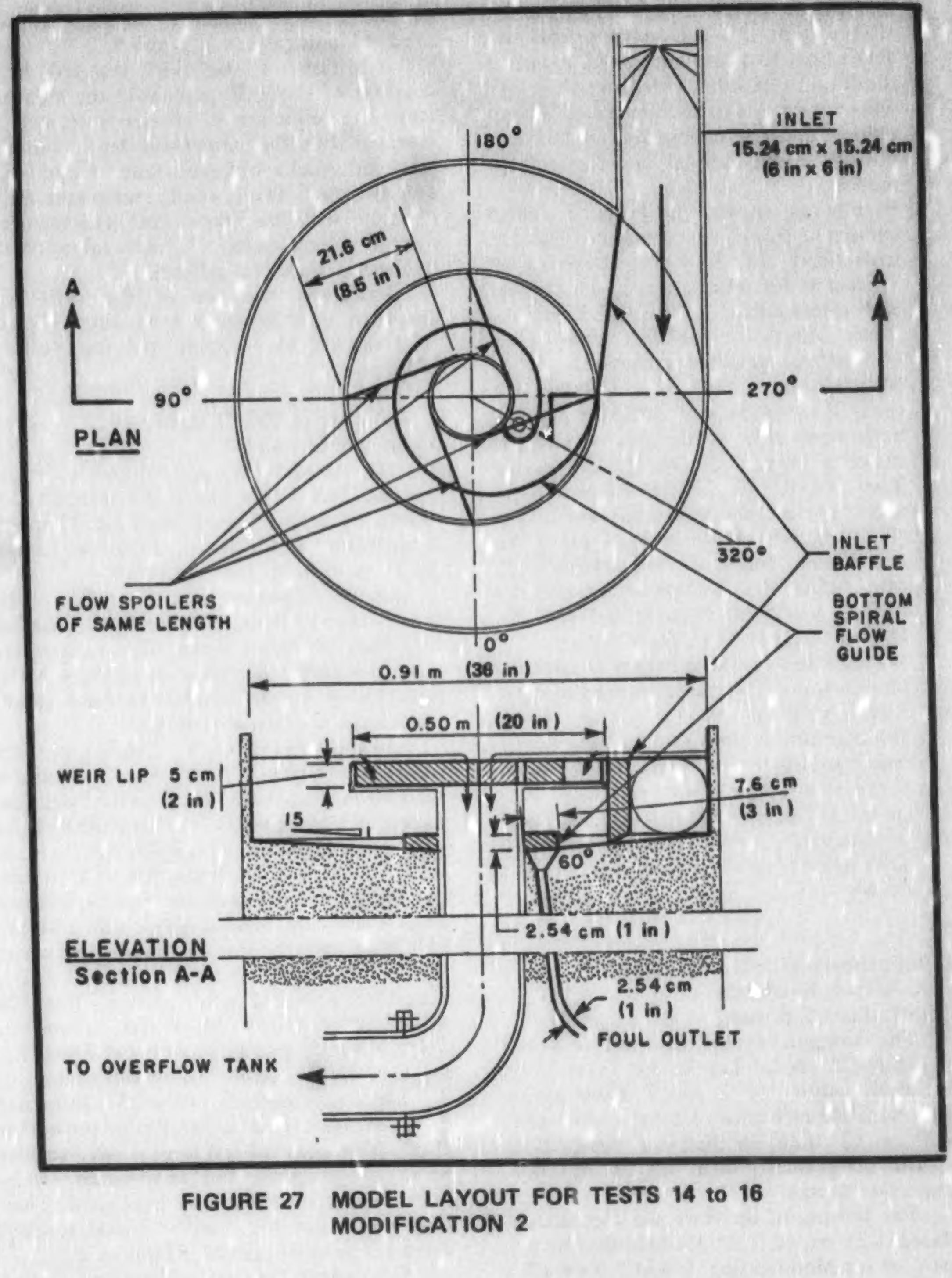

INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
180°
21.6 cm
(8.5 in)
A
A
90°
270°
PLAN
320°
INLET
BAFFLE
BOTTOM
SPIRAL
FLOW
GUIDE
FLOW SPOILERS
OF SAME LENGTH
0°
0.91 m (36 in)
0.50 m (20 in)
WEIR LIP 5 cm
(2 in)
15
7.6 cm
(3 in)
60°
2.54 cm (1 in)
ELEVATION
Section A-A
2.54 cm
(1 in)
FOUL OUTLET
TO OVERFLOW TANK

FIGURE 27 MODEL LAYOUT FOR TESTS 14 to 16
MODIFICATION 2

the foul outlet, also shown in Figure 27, Modification 2. The purpose of this device was to help concentrate a part of the flow around the central overflow pipe where weak velocities prevailed, and to reduce the solids deposits on the chamber bottom during normal operation of the model.

Results as shown in Table 3, when compared to previous values for Stage 1, indicated an 18-percent drop of efficiency for small 3 l/sec (0.8 gal/sec) and intermediate 5 l/sec (1.3 gal/sec) flows. Values for the high flow 7 l/sec (1.8 gal/sec) remained unchanged.

Modifications 3 and 4 included the same spiral flow guide with different heights; both were open at the four outlet. As shown in Figure 28, Model Layout for Tests 17 to 19, Modifications 3, the height of the spiral flow guide was 2.2 cm (0.87 in) above the chamber floor at the foul outlet. This is shown in Figure 29, Inlet Baffle, Modification 3. It was raised to 7.6 cm (3.0 in) as shown in Figure 30, Model Layout for Tests 20 to 22, Modification 4; and in Figure 31, Details, Modification 4. Results showed a slight improvement with respect to Modification 2, but the best efficiency rate was still 8 percent below the values obtained in Stage 1, with no special flow guide, and deposits of solids at the small flow were still not eliminated. This device was discarded in the ensuing tests for this reason.

2. Influence of a Concentric Skirt for Collecting Floatables – Modifications 5, 6, and 7

The configuration for these tests is shown in Figure 32, Model Layout for Tests 23 to 31, Modifications 5, 6, and 7. These stages dealt with the influence of a concentric skirt, 61.0 cm (24.0 in) in diameter, designed to retain floatables when set at different immersion depths.

The bottom of the skirt was successively placed 1.25 cm (0.5 in) Modification 5; 2.5 cm (1.0 in) Modification 6; and 5.0 cm (2.0 in) Modification 7; below the water level in the chamber. Weir diameter and inlet baffle conditions were similar to those previously used in Modifications 2, 3, and 4.

Addition of the skirt resulted in a decrease of about 30 percent in the recovery rate. The reduction in efficiency seemed to increase with the immersion depth, but the scattered results obtained failed to define a specific trend. The poorest results were those obtained with the 5.0 cm (2.0 in) immersion depth, Modification 7, and intermediate discharge 5 l/sec (1.3 gal/sec).

Therefore, the use of the skirt was discarded in subsequent tests and floatables were allowed to discharge with the overflow effluent.

3. Influence of Weir Diameter – Modifications 8 and 9

These modifications are shown in Figures 24a and 24b, Model Layout for tests 2 to 13; Figure 33, Model Layout for Tests 32 to 35, Modification 8; and Figure 34, Model Layout for Tests 36 to 38, Modification 9.

Smaller diameter weirs provide a wider area between the weir lip and the chamber wall than do larger weirs. This reduces the upward velocity component, giving a better opportunity for the simulated erosion runoff particles in suspension to settle.

On the other hand, the distance from the central overflow pipe to the weir lip or crest is reduced in proportion when smaller weirs are used and, consequently, the time allowed for particles in suspension under the weir to settle is shortened. On the basis that an optimum size must exist, decision was made to test two additional weirs: one had a weir with a 61 cm-(24 in) diameter, Modification 8, shown in Figure 33, Model Layout for Tests 32 to 35. The other provided a weir with a 71 cm-(28 in) diameter. Figure 34, Model Layout for Tests 36 to 38, Modification 9; and Figure 35, Details – Modification 7; show this change.

Results, as plotted in Figure 36, Influence of Weir-Chamber Diameter Ratio, show that the differences in efficiency are smaller between the small and intermediate weirs than when the largest weir is utilized. They show also that the maximum was reached when a weir of 61 cm (24 in) was used.

Subsequent tests were, therefore, carried out with a weir-chamber diameter ratio of 2:3.

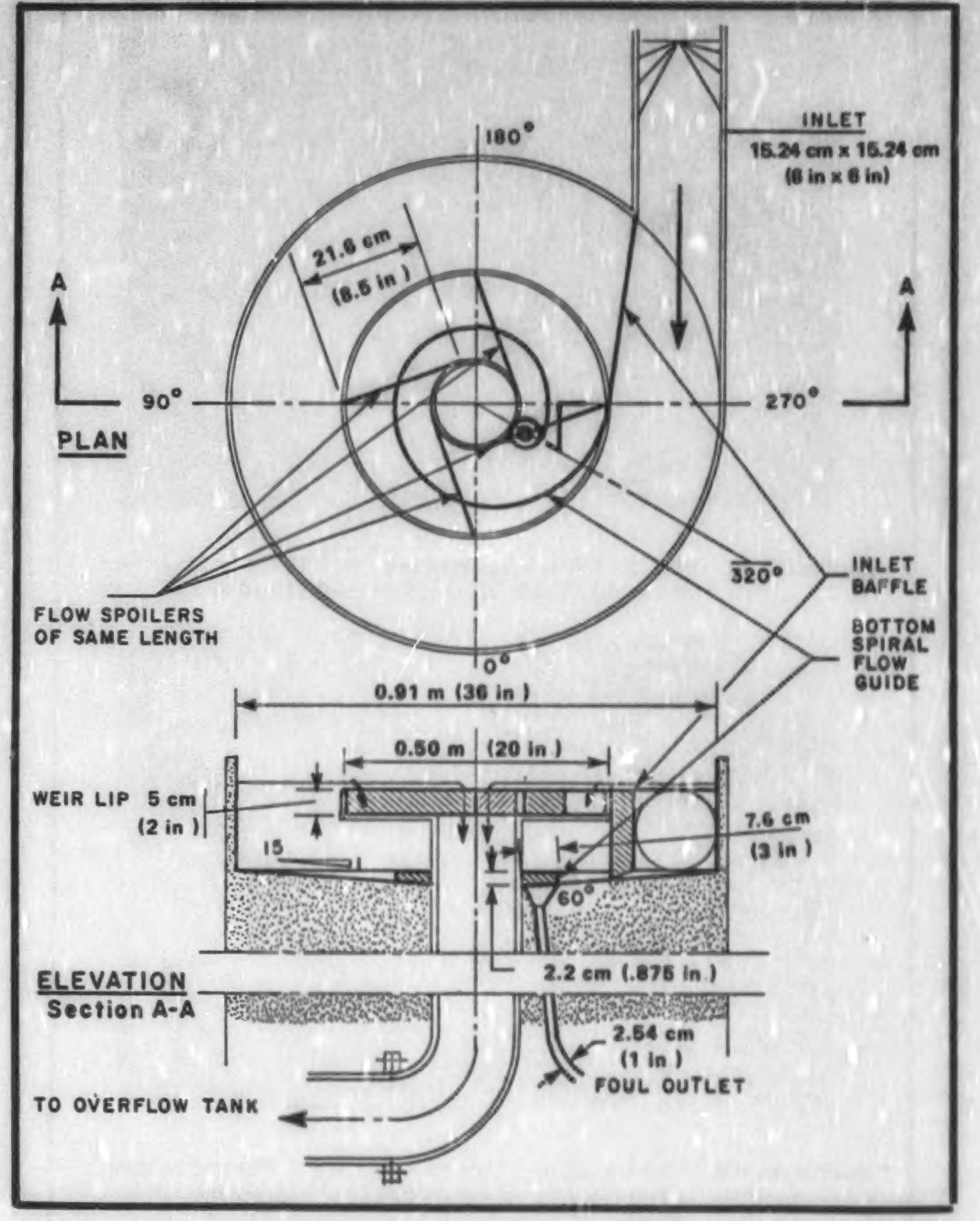
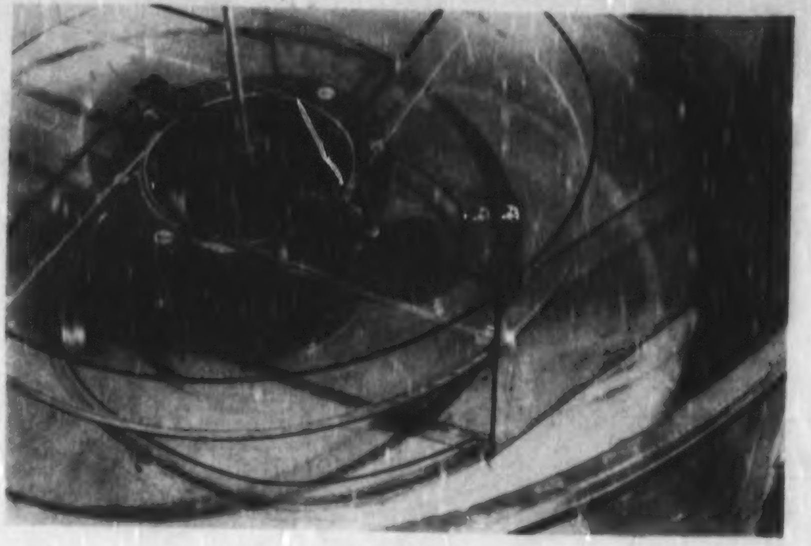
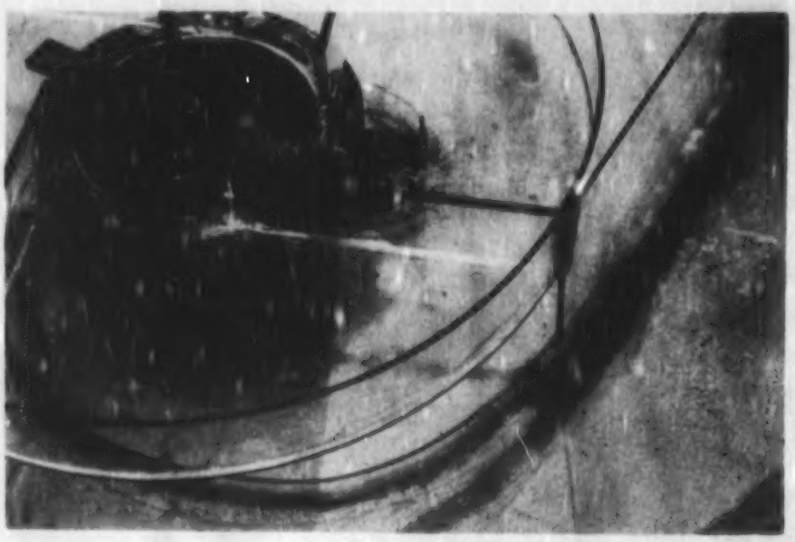

INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
180°
21.6 cm
(8.5 in)
A
A
90°
270°
PLAN
320°
INLET
BAFFLE
BOTTOM
SPIRAL
FLOW
GUIDE
FLOW SPOILERS
OF SAME LENGTH
0°
0.91 m (36 in)
0.50 m (20 in)
WEIR LIP 5 cm
(2 in)
15
7.6 cm
(3 in)
60°
2.2 cm (.875 in.)
ELEVATION
Section A-A
2.54 cm
(1 in)
FOUL OUTLET
TO OVERFLOW TANK

FIGURE 28 MODEL LAYOUT FOR TESTS 17-19
MODIFICATION 3



Modification 2: 50.3 cm (20 in) diameter weir. Inlet Baffle and bottom. Spiral Flow Guide 2.5 cm (1 in) high closed at foul outlet.



Modification 3: 50.3 cm (20 in) diameter weir. Inlet Baffle and bottom. Spiral Flow Guide 2.2 cm (0.87 in) high open at foul outlet.

FIGURE 29 INLET BAFFLE, MODIFICATION 3

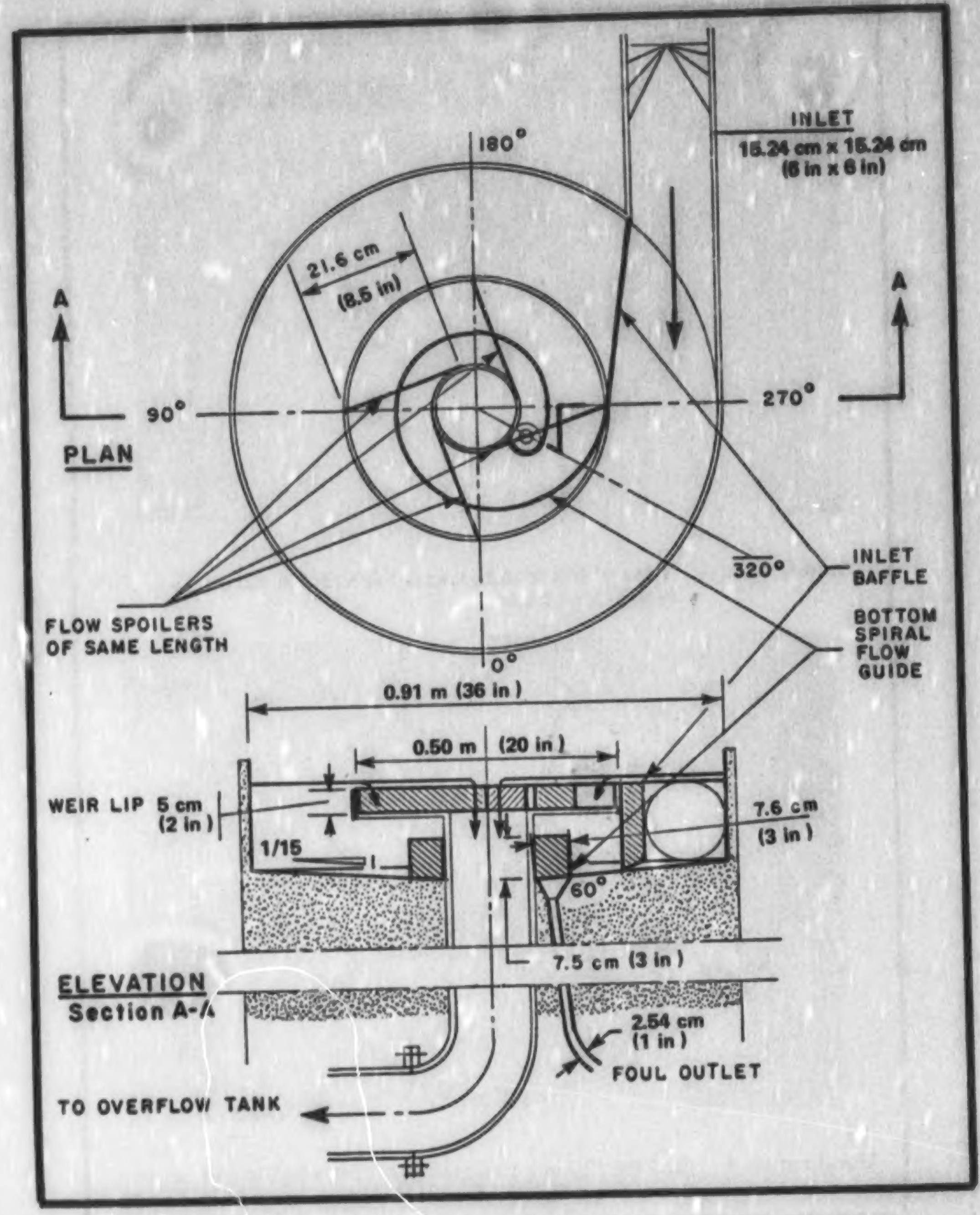
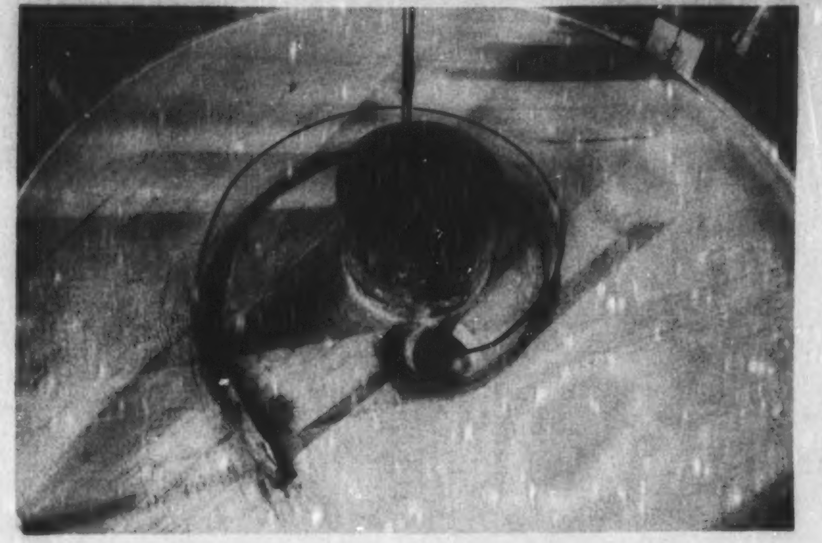
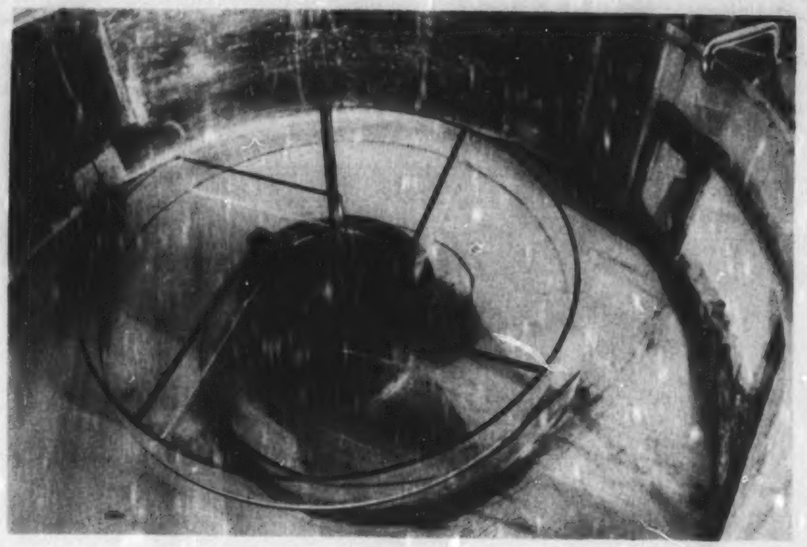

INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
180°
21.6 cm
(8.5 in)
A
A
90°
270°
PLAN
320°
INLET BAFFLE
BOTTOM SPIRAL FLOW GUIDE
FLOW SPOILERS OF SAME LENGTH
0°
0.91 m (36 in)
0.50 m (20 in)
WEIR LIP 5 cm (2 in)
1/15
7.6 cm
(3 in)
60°
7.5 cm (3 in)
ELEVATION
Section A-A
2.54 cm
(1 in)
FOUL OUTLET
TO OVERFLOW TANK

FIGURE 30 MODEL LAYOUT FOR TESTS 20 to 22
MODIFICATION 4



Modification 4: View of the bottom spiral. Flow Guide 7.5 cm (3 in) high at foul outlet.



Modification 4: 50.3 cm (20 in) diameter weir. Inlet Baffle and bottom. Spiral Flow Guide 7.5 cm (3 in) high open at foul outlet.

FIGURE 31 DETAILS, MODIFICATION 4

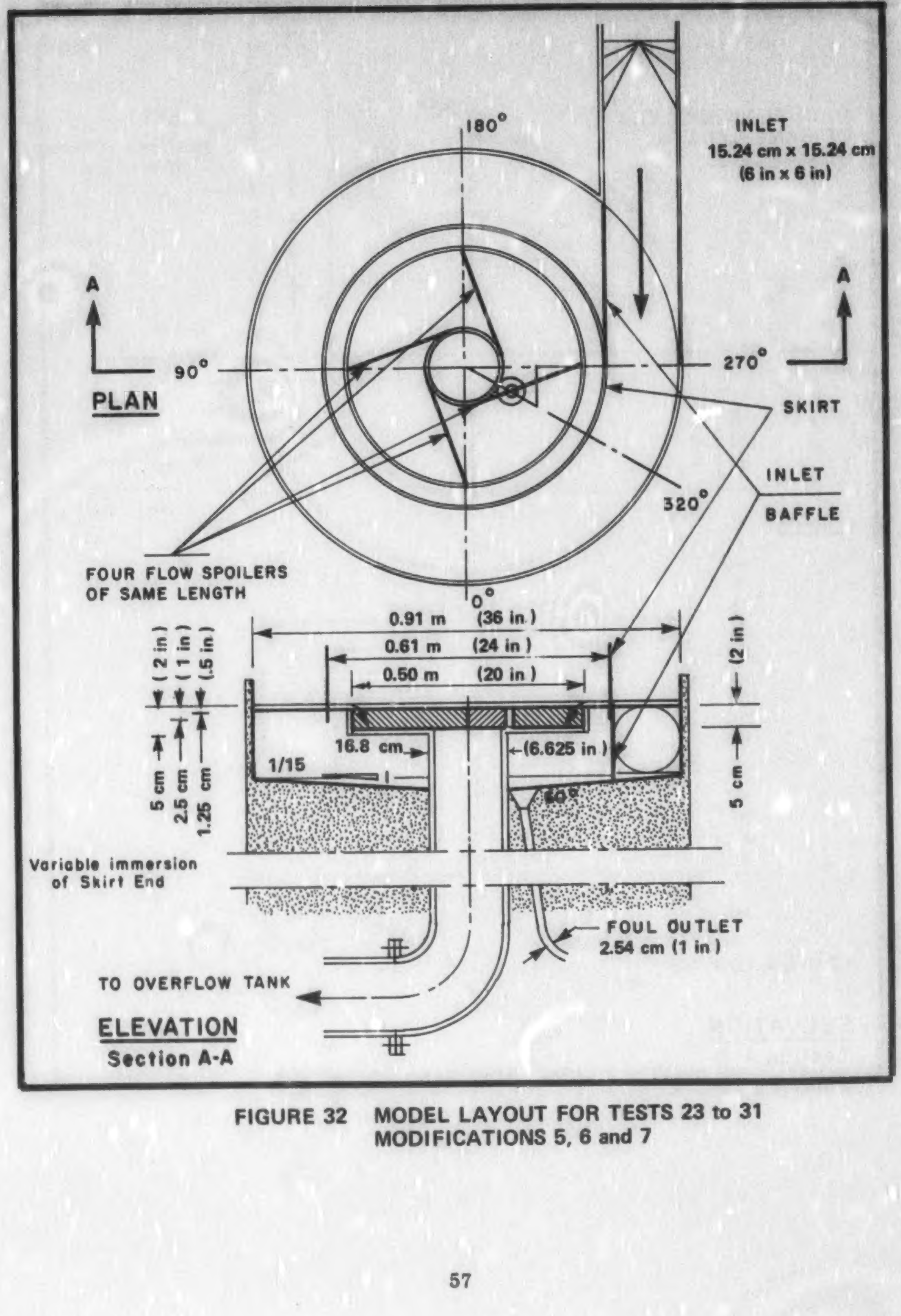

INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
180°
A
A
90°
270°
PLAN
SKIRT
INLET
BAFFLE
320°
FOUR FLOW SPOILERS
OF SAME LENGTH
0°
0.91 m (36 in)
0.61 m (24 in)
0.50 m (20 in)
(2 in)
(1 in)
(.5 in)
5 cm
2.5 cm
1.25 cm
(2 in)
5 cm
16.8 cm
(6.625 in)
1/15
60°
Variable immersion
of Skirt End
FOUL OUTLET
2.54 cm (1 in)
TO OVERFLOW TANK
ELEVATION
Section A-A

FIGURE 32 MODEL LAYOUT FOR TESTS 23 to 31
MODIFICATIONS 5, 6 and 7

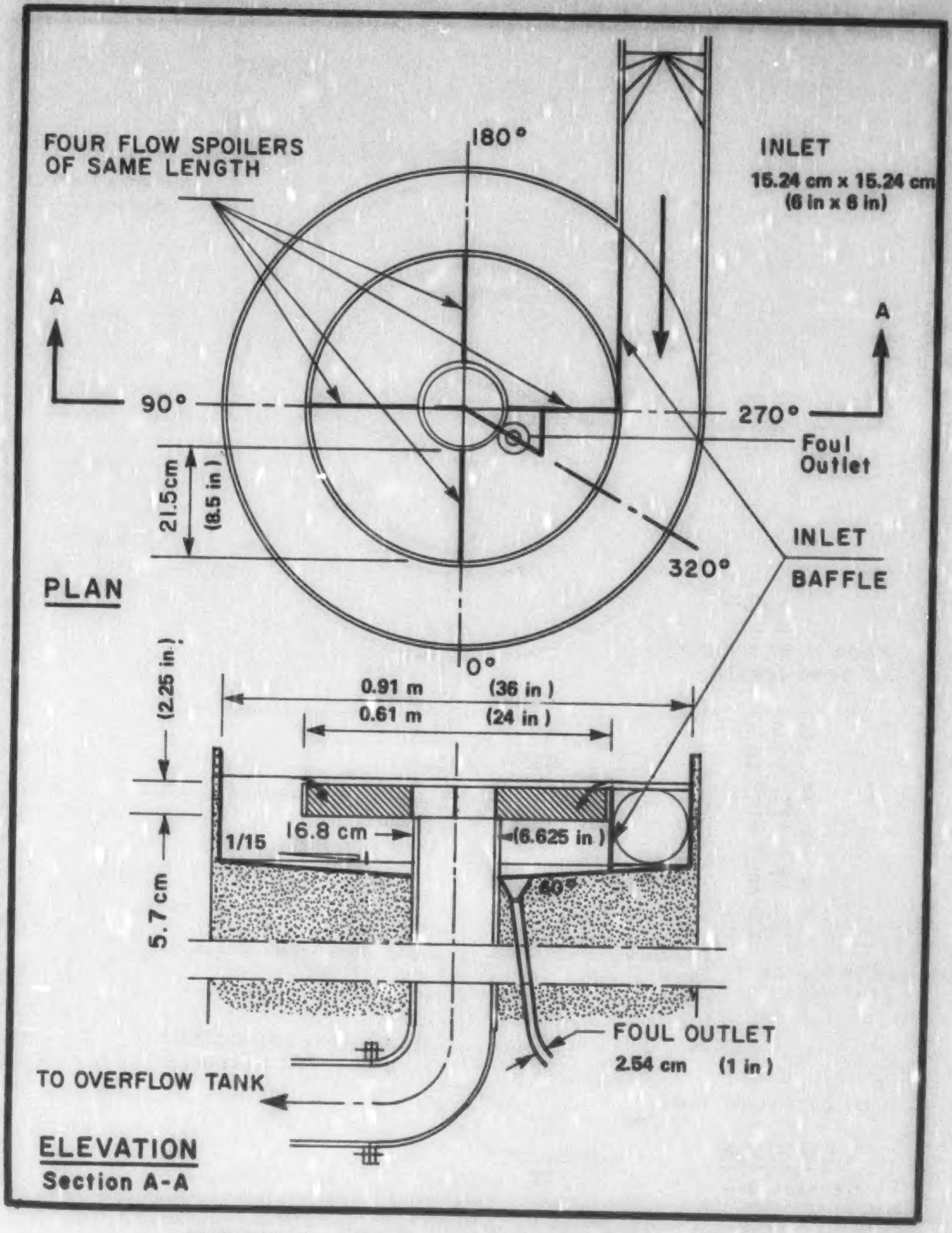

FOUR FLOW SPOILERS OF SAME LENGTH
180°
INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
A
A
90°
270°
Foul Outlet
21.5cm
(8.5 in)
INLET
BAFFLE
320°
PLAN
0°
(2.25 in.)
0.91 m
(36 in)
0.61 m
(24 in)
1/15
16.8 cm
(6.625 in)
60°
5.7 cm
FOUL OUTLET
2.54 cm (1 in)
TO OVERFLOW TANK
ELEVATION
Section A-A

FIGURE 33 MODEL LAYOUT FOR TESTS 32 to 35
MODIFICATION 8

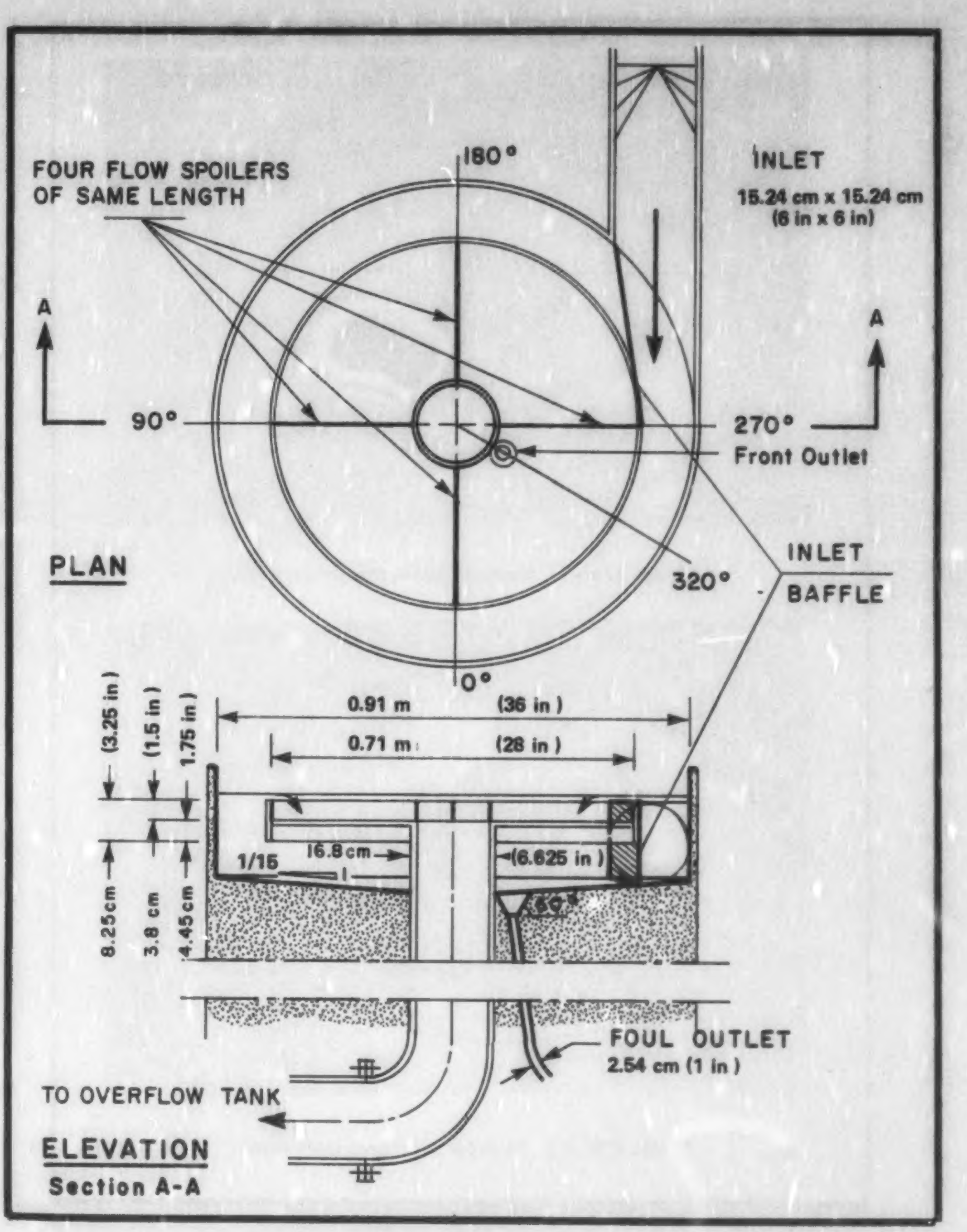
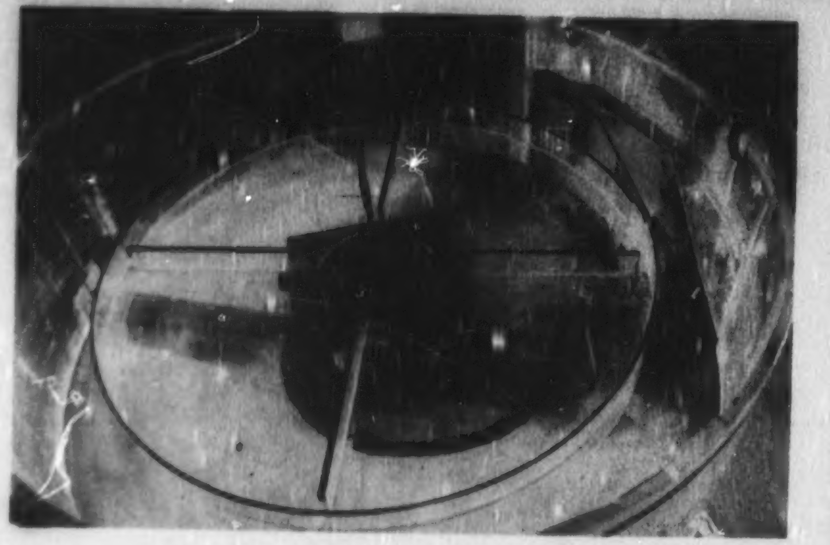
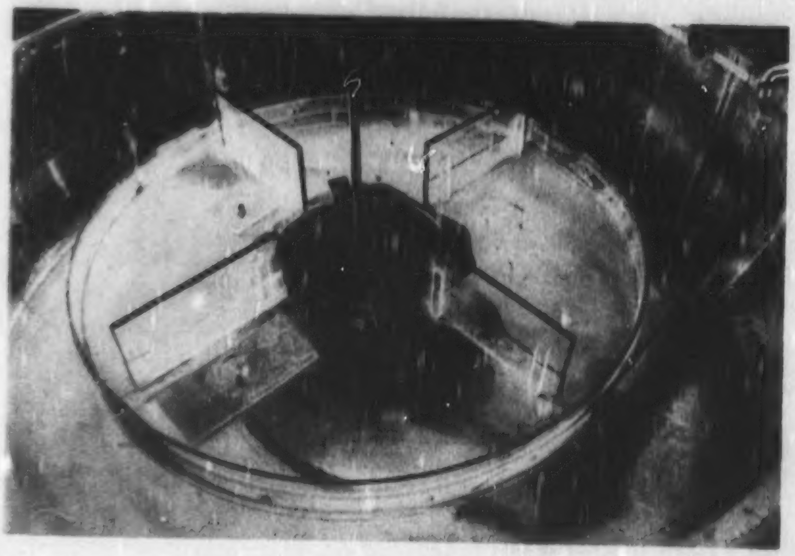

FOUR FLOW SPOILERS OF SAME LENGTH
180°
INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
A
A
90°
270°
Front Outlet
PLAN
320°
INLET
BAFFLE
0°
0.91 m
(36 in)
0.71 m
(28 in)
(3.25 in)
(1.5 in)
(1.75 in)
8.25cm
3.8 cm
4.45 cm
1/15
16.8cm
(6.625 in)
60°
FOUL OUTLET
2.54 cm (1 in)
TO OVERFLOW TANK
ELEVATION
Section A-A

FIGURE 34 MODEL LAYOUT FOR TESTS 36 to 38
MODIFICATION 9



61 cm (24 in) diameter weir and inlet baffle



71 cm (28 in) diameter weir and inlet baffle

FIGURE 35 DETAILS, MODIFICATION 7

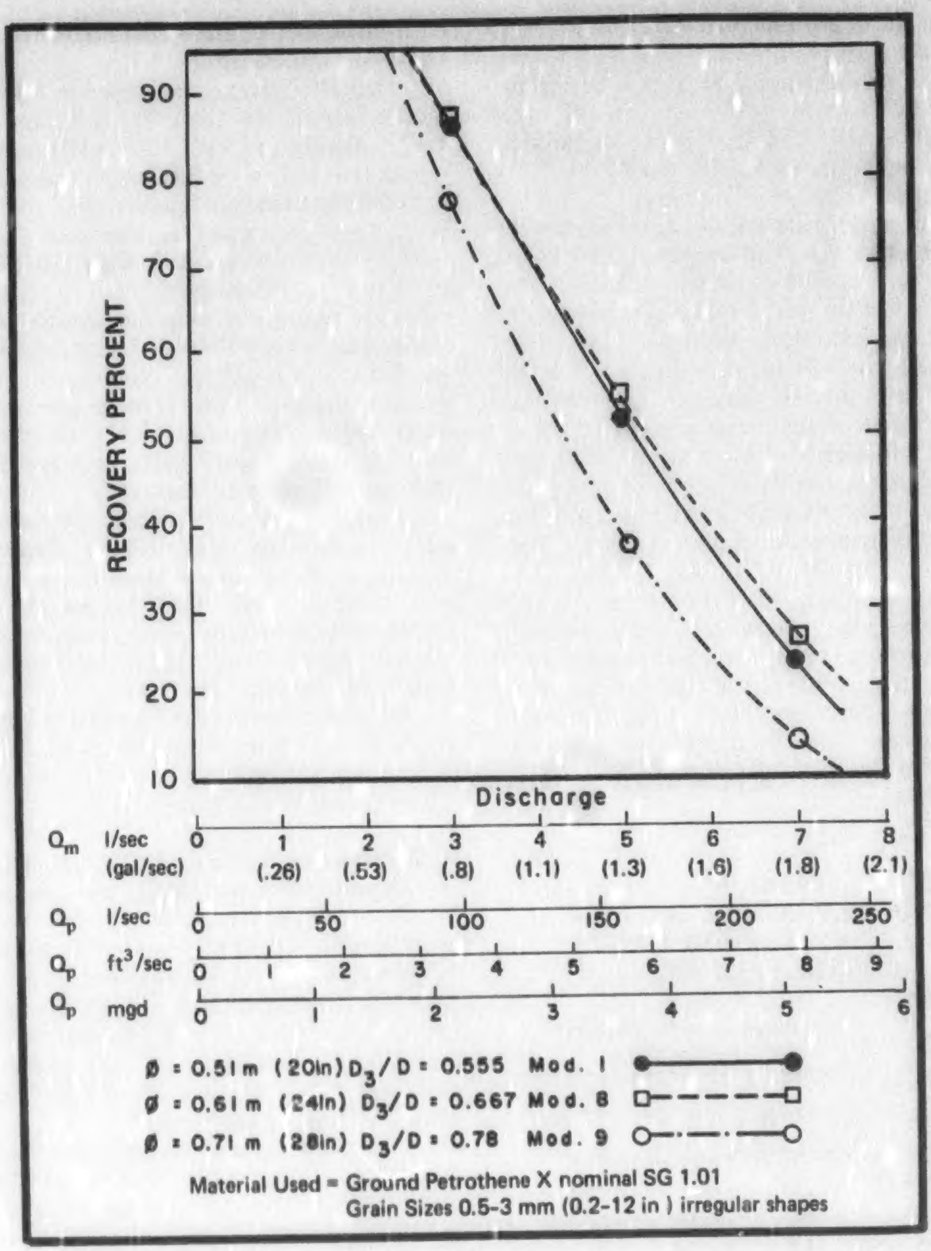


FIGURE 36 INFLUENCE OF WEIR – CHAMBER DIAMETER RATIO
(All tests carried out with inlet baffle)
1:15 CHAMBER FLOOR SLOPE AND 5 PERCENT DRAW-OFF

4. Influence of the Chamber Floor Slope – Modification 10

These modifications are shown in Figure 37, Model Layout for Tests 39 to 41, Modification 10; and in Figure 38, Model Layout for Tests 42 to 59 and 69 to 107, Modification 11.

Since cattle watering tanks are suggested as an economical way to construct these swirl chamber units, studies were undertaken to test the effect on the recovery rate produced by a flat chamber floor. Both the 51 cm- (20 in) and 61 cm- (24 in) diameter weirs were tested with 5 percent draw-off. Only results relevant to the second weir are presented in Figure 39, Influence of Chamber Floor Slope. It shows that a flat floor is not as efficient. Recovery rates decreased, as indicated by Table 4, Comparable Recovery Rates for Sloping and Horizontal Chamber Floors.

Table 4 indicates that the 61 cm- (24 in) diameter weir had smaller losses, and yielded better recovery rates for intermediate and high discharges when the floor slope was eliminated. Therefore, this weir diameter should be considered for design purposes with either a flat chamber bottom or with the 1:15 sloping floor.

TABLE 4
COMPARABLE RECOVERY RATES FOR SLOPING AND HORIZONTAL CHAMBER FLOORS

	Recovery Rates (Percent) at Rate of Flow		
Model discharge l/sec (ft^3/sec)	3 (0.11)	5 (0.18)	7 (0.25)
A. Tests of recovery rates performed with a 51 cm (20 in) ϕ Weir:			
slope of 1/15	86	52	22
horizontal floor	66	37	15
absolute loss	20	15	7
relative loss	23	29	31
B. Tests of recovery rates performed with a 61 cm (24 in) ϕ Weir:			
slope of 1/15	87	54	20
horizontal floor	66	44	23
absolute loss	21	10	3
relative loss	24	19	11

5. Influence of Continuous Underflow Draw-Off, Modification 11

This configuration is shown in Figure 38, Model Layout for Tests 42 to 59 and 69 to 107, Modification 11. Although the preceeding tests were all carried out with a 5 percent continuous underflow, additional tests were performed at increased draw-off rates. The rates selected were 10 and 20 percent of the discharge.

The foul outlet pipe was unable to pass the 1,400-cm^3/sec (85.4 in^3/sec) required for the 7 l/sec (1.8 gal/sec) discharge at the 20 percent draw-off rate. The maximum rate evacuated was 14 percent; therefore, the same rate was applied respectively to 3 and 5 l/sec (0.8 and 1.3 gal/sec) discharges.

Results, as plotted in Figure 40, Influence of Continuous Underflow Draw-off, Modification 11, show that the efficiency increased with the draw-off. This phenomenon seemed more pronounced for small discharges 3 l/sec (0.8 gal/sec) than for a high 7 l/sec (1.8 gal/sec) rate.

Of importance is the fact that deposits of solids on the bottom of the swirl chamber disappeared gradually as the underflow draw-off rate was increased.

6. Influence of Inlet Size Modification 12

Conditions represented by Figure 41, Model Layout for Tests 60 to 68, Modification 12, were similar to those for Modification 11, except that the square inlet pipe was reduced to 10.1 cm (4 in) instead of the 15.2 cm (6 in) previously used. The same draw-off, representing 5 percent of the total discharge, was maintained so the results would be directly comparable.

The recovery rate for the two sizes of pipe inlets are shown in Figure 42, Influence of Inlet Size. Although the same inlet baffle was used, Figure 41 shows that efficiency of the swirl chamber dropped significantly when the inlet velocity was increased. Consequently, the 15.2 cm x 15.2 cm (6 in x 6 in) inlet was installed in the model for further tests.

Tests Carried Out with Petrothene Dust – SG 1.01

$0.12 \text{ mm} < d < 0.5 \text{ mm}$ $(0.005 < d < 0.2 \text{ in})$

After the model had been set up for

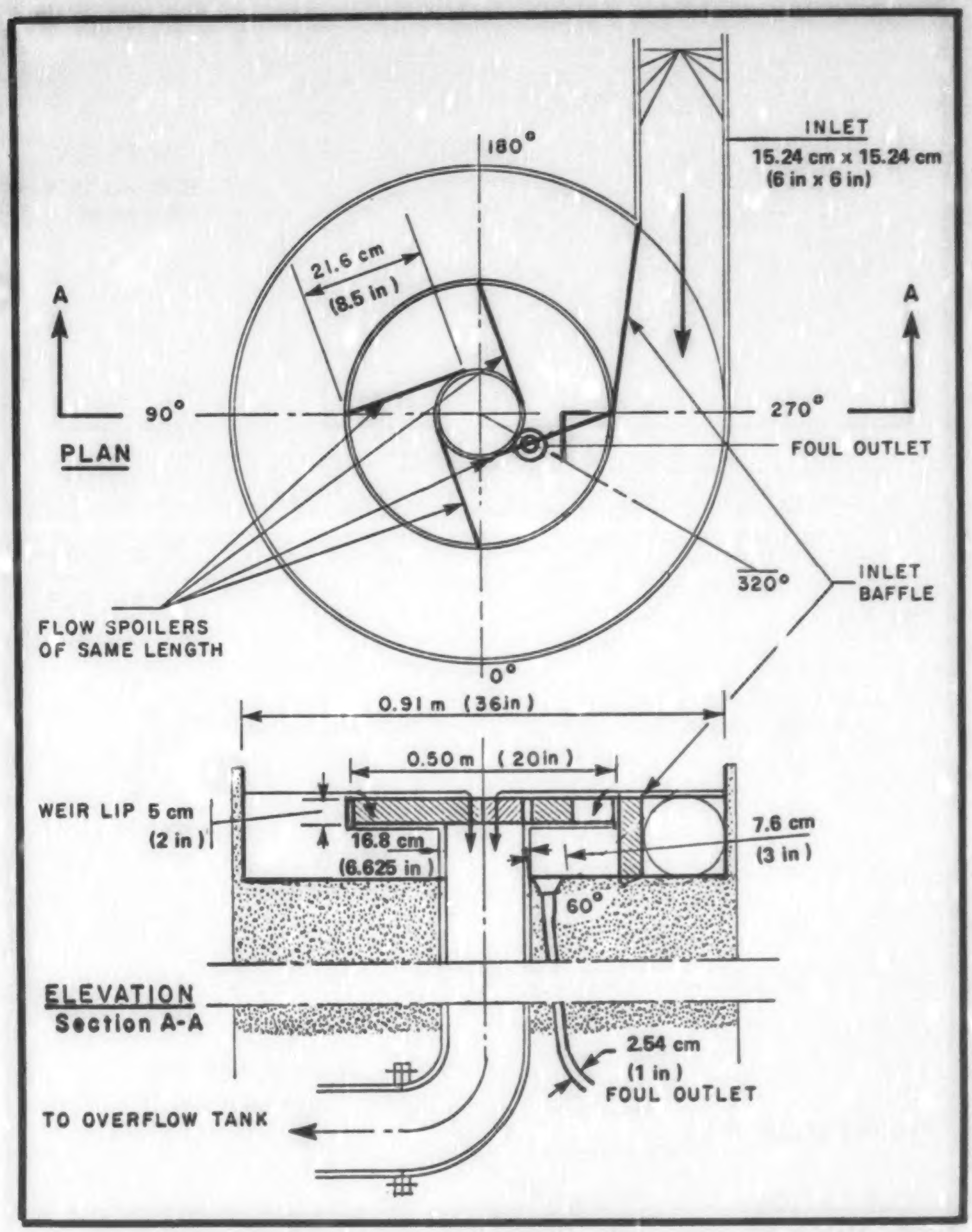

INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
180°
21.6 cm
(8.5 in)
A
A
90°
270°
PLAN
FOUL OUTLET
320°
INLET
BAFFLE
FLOW SPOILERS
OF SAME LENGTH
0°
0.91 m (36in)
0.50 m (20in)
WEIR LIP 5 cm
(2 in)
16.8 cm
(6.625 in)
7.6 cm
(3 in)
60°
ELEVATION
Section A-A
2.54 cm
(1 in)
FOUL OUTLET
TO OVERFLOW TANK

FIGURE 37 MODEL LAYOUT FOR TESTS 39 TO 41
MODIFICATION 10

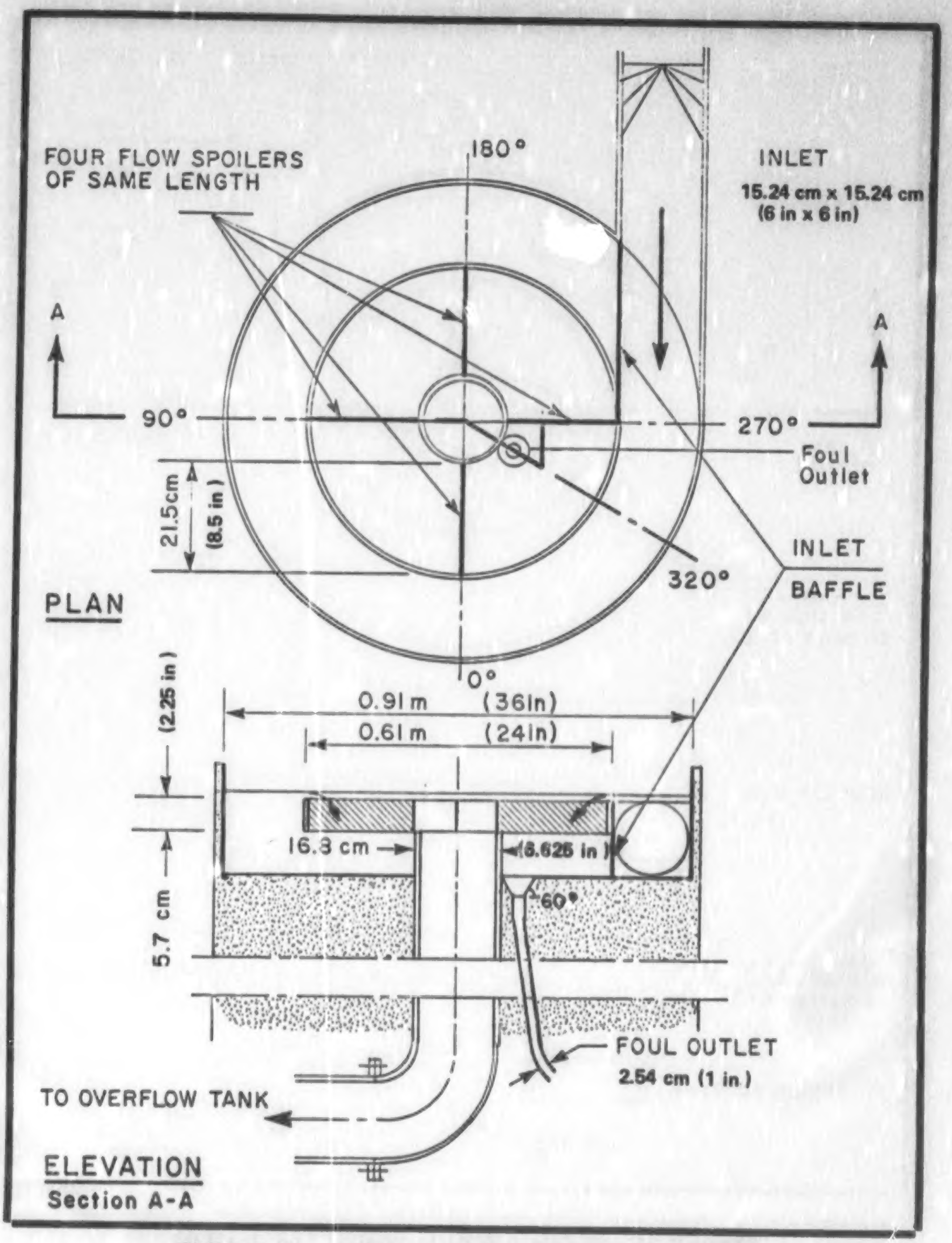

FOUR FLOW SPOILERS OF SAME LENGTH
180°
INLET
15.24 cm x 15.24 cm
(6 in x 6 in)
A
A
90°
270°
Foul Outlet
21.5cm
(8.5 in)
INLET
BAFFLE
320°
PLAN
0°
(2.25 in)
0.91 m (36in)
0.61 m (24in)
16.8 cm
(6.625 in)
60°
5.7 cm
FOUL OUTLET
2.54 cm (1 in)
TO OVERFLOW TANK
ELEVATION
Section A-A

FIGURE 38 MODEL LAYOUT FOR TESTS 42 TO 59 AND 69 TO 107 MODIFICATION 11

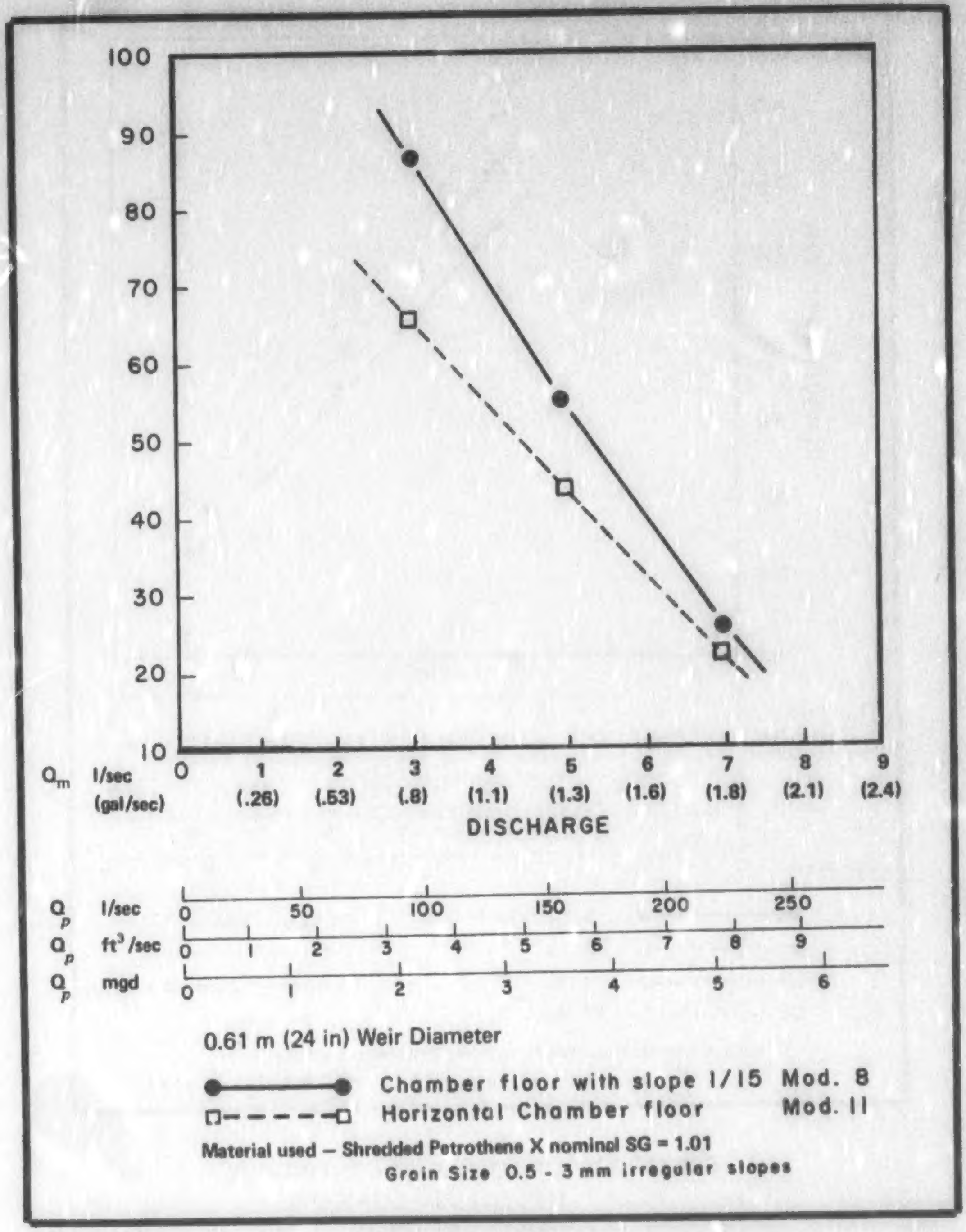
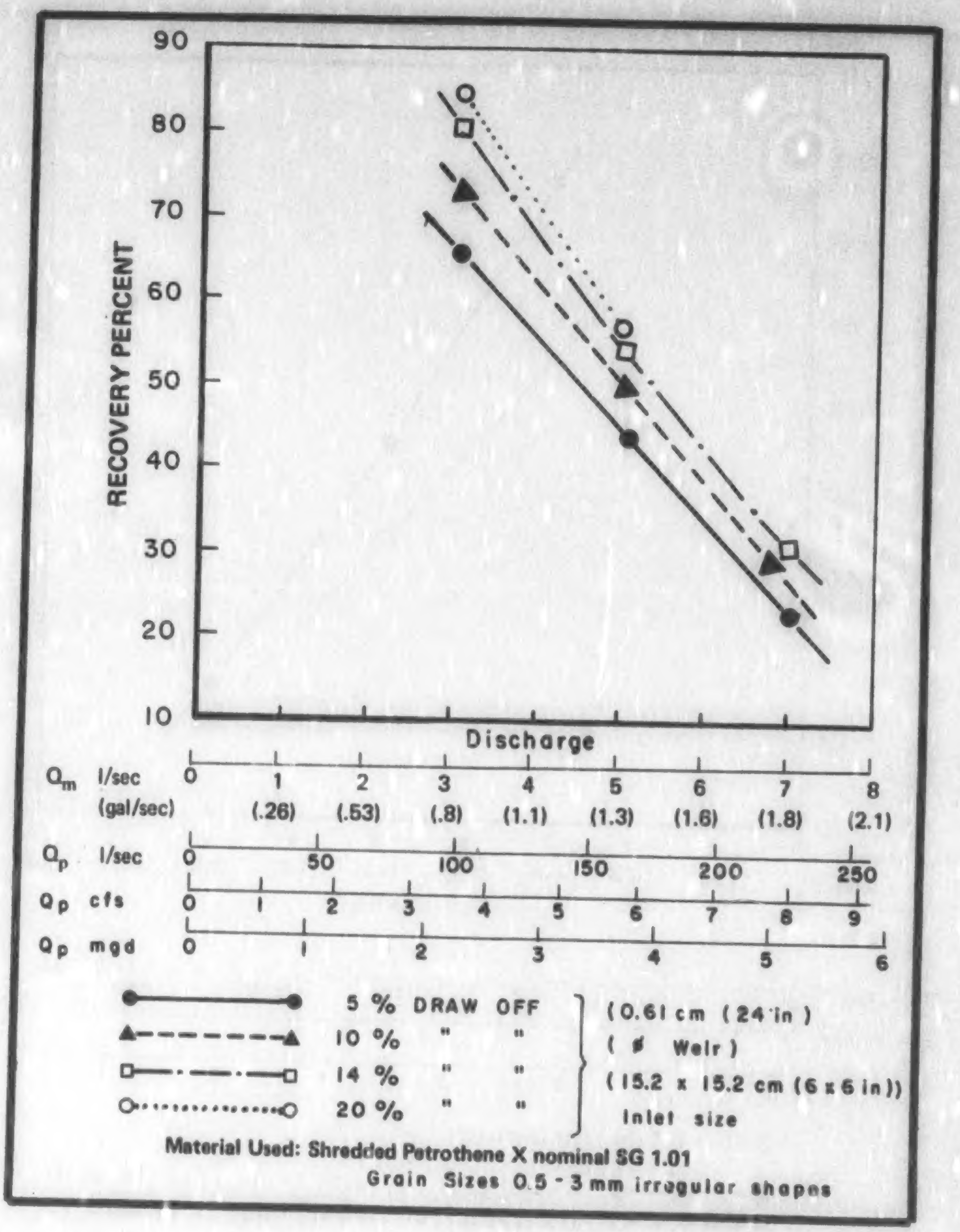


FIGURE 39 INFLUENCE OF CHAMBER FLOOR SLOPE
(All tests carried out with inlet baffle
and 5 percent Draw-off)



Material Used: Shredded Petrothene X nominal SG 1.01
Grain Sizes 0.5 - 3 mm irregular shapes

FIGURE 40 INFLUENCE OF CONTINUOUS UNDERFLOW DRAW-OFF MODIFICATION 11

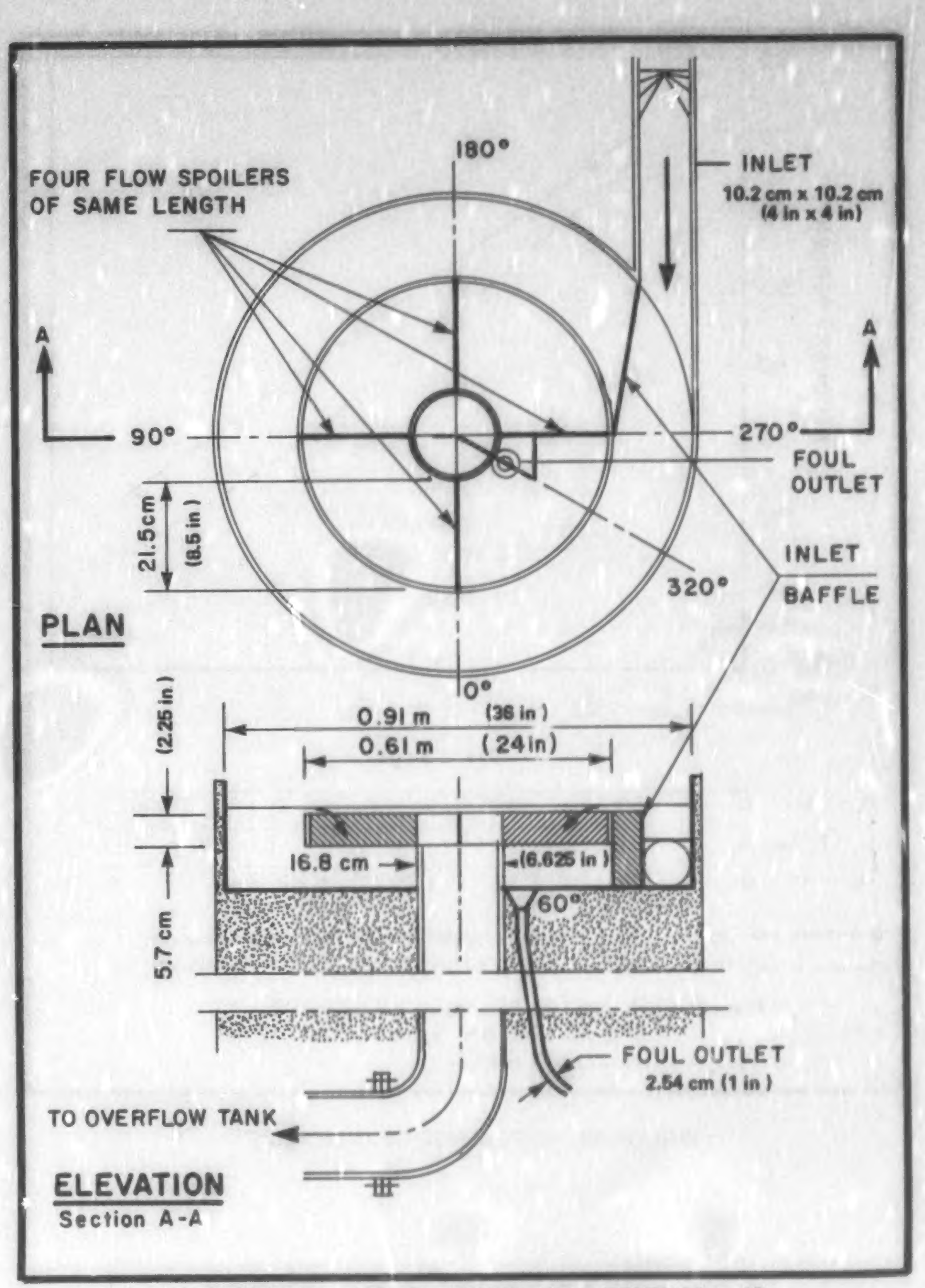
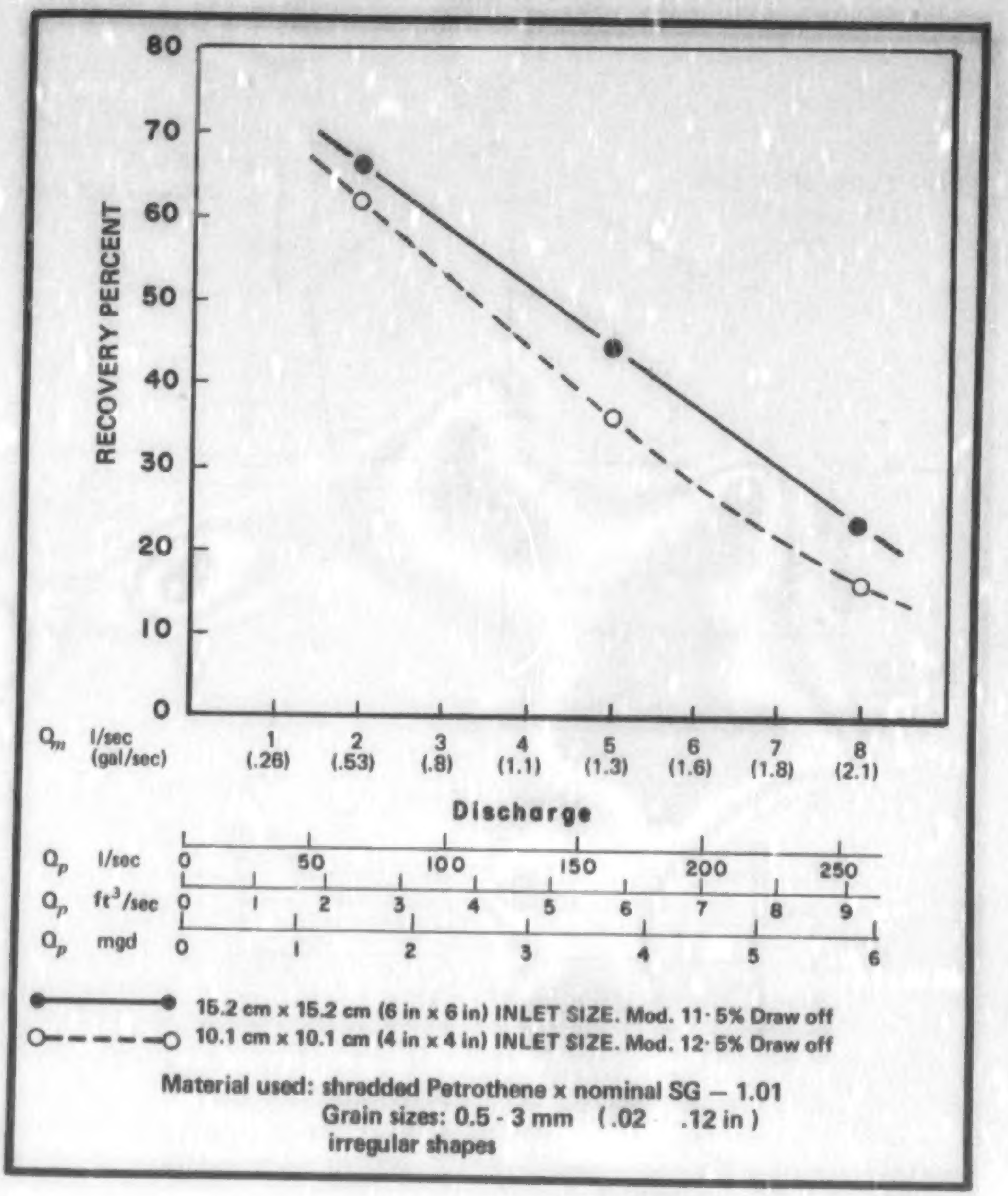

180°
FOUR FLOW SPOILERS
OF SAME LENGTH
INLET
10.2 cm x 10.2 cm
(4 in x 4 in)
A
A
90°
270°
FOUL
OUTLET
21.5cm
(8.5 in)
INLET
BAFFLE
320°
PLAN
0°
(2.25 in)
0.91 m
(36 in)
0.61 m
(24 in)
16.8 cm
(6.625 in)
60°
5.7 cm
FOUL OUTLET
2.54 cm (1 in)
TO OVERFLOW TANK
ELEVATION
Section A-A

FIGURE 41 MODEL LAYOUT FOR TESTS 60 to 68
MODIFICATION 12 – SG 2.65



Material used: shredded Petrothene x nominal SG — 1.01
Grain sizes: 0.5 - 3 mm (.02 .12 in)
irregular shapes

FIGURE 42 INFLUENCE OF INLET SIZE

optimum recovery, a new series of tests was carried out with Petrothene dust. The configuration corresponding to Modification 1, Figure 23, was used, namely a 15.2 cm x 15.2 cm (6 in x 6 in) square inlet, and a 0.61 m (2 ft) diameter weir with 5.7 cm (2.25 in) lip. The crest of the lip was set at the same elevation as the inlet crown; the flat chamber floor was retained.

The series of tests involved the use of the three respective discharges – 3, 5, and 7 l/sec (0.8, 1.3, and 1.8 gal/sec) in the model with varying draw-off rates (5, 10, and 14 percent). This total of nine additional tests completed the data necessary to prepare the curves in Figures 43, 44, and 45, Suggested Recovery Curves for Gilsonite and Petrothene in Model with 5 percent, 10 percent, and 14 percent Draw-off, respectively.

Predicted Prototype Grit Recovery

As mentioned, the recovery curves attained for the Gilsonite and Petrothene in the model studies are as shown in Figures 43, 44, and 45.

For the three model discharges used in the tests, the corresponding recovery rates are given in Table 5, Percent Suggested Recovery in Model.

The recovery rates have been expressed as a function of the particle settling velocity, to provide for more effective use of the curves. Plotting according to this method gave the curves represented in Figures 6, 7, and 8.

The advantage of this method of presentation is that it allows a precise interpolation for particle settling velocities lying within the range of the materials used. For example, to find the recovery rate corresponding to a particle whose settling velocity is 0.5 cm/sec (0.2 in/sec) with 10 percent draw-off, the values can be found in Figure 33 on the vertical 0.5 cm/sec (0.2 in/sec) at the respective intersections with the 3, 5, and 7 l/sec (0.8, 1.3, and 1.8 gal/sec) discharges. Results are 66, 42, and 21 percent, respectively.

The final steps in calculating the predicted prototype recoveries are as follows:

a. For a given model particle settling velocity in either Figure 6, 7, or 8. To find the recovery rate for a given discharge.
b. Multiply the particle settling velocity by the velocity scale, $\sqrt{4} = 2$, to find the particle settling velocity in the prototype.
c. Use Figure 5 with this prototype particle settling velocity and find the corresponding grit size for SG 2.65.
d. Multiply the given discharge in (a), above, by the discharge scale $4^{5/2} = 32$ to find the prototype discharge.
e. Plot the grit particle size (c) as a function of discharge (d) and recovery rate (a) in Figures 9, 10, or 11.

An example can be followed through this procedure: in Figure 8, take the particle settling velocity of 0.8 cm/sec (0.3 in/sec) with a model discharge of 5 l/sec (1.3 gal/sec). This shows a recovery rate of 54 percent. These particles in the prototype would have a settling velocity of 2 x 0.8 = 1.6 cm/sec (0.63 in/sec). In Figure 5, this gives a grit particle size of 0.16 mm (0.006 in) or 160μ. Multiplying the model discharge of 5 l/sec (1.3 gal/sec) by 32 gives 160 l/sec (42.2 gal/sec). The particle size, discharge, and recovery rate then define one point in Figure 11, as shown.

A network of points was calculated for each of the draw-off rates to give the families of curves in Figures 9, 10, 11.

TABLE 5
PERCENT SUGGESTED RECOVERY IN MODEL

Discharge model		Gilsonite			Shredded Petrothene			Petrothene Dust		
		Draw-off			Draw-off			Draw-off		
l/sec	gal/sec	5%	10%	14%	5%	10%	14%	5%	10%	14%
3	(0.8)	99.5	99.5	99.5	66	73	81	46	52	56
5	(1.3)	89	93	95	44	50	54	25	28.5	33
7	(1.8)	67	75	84	23	27	31	12	14	18

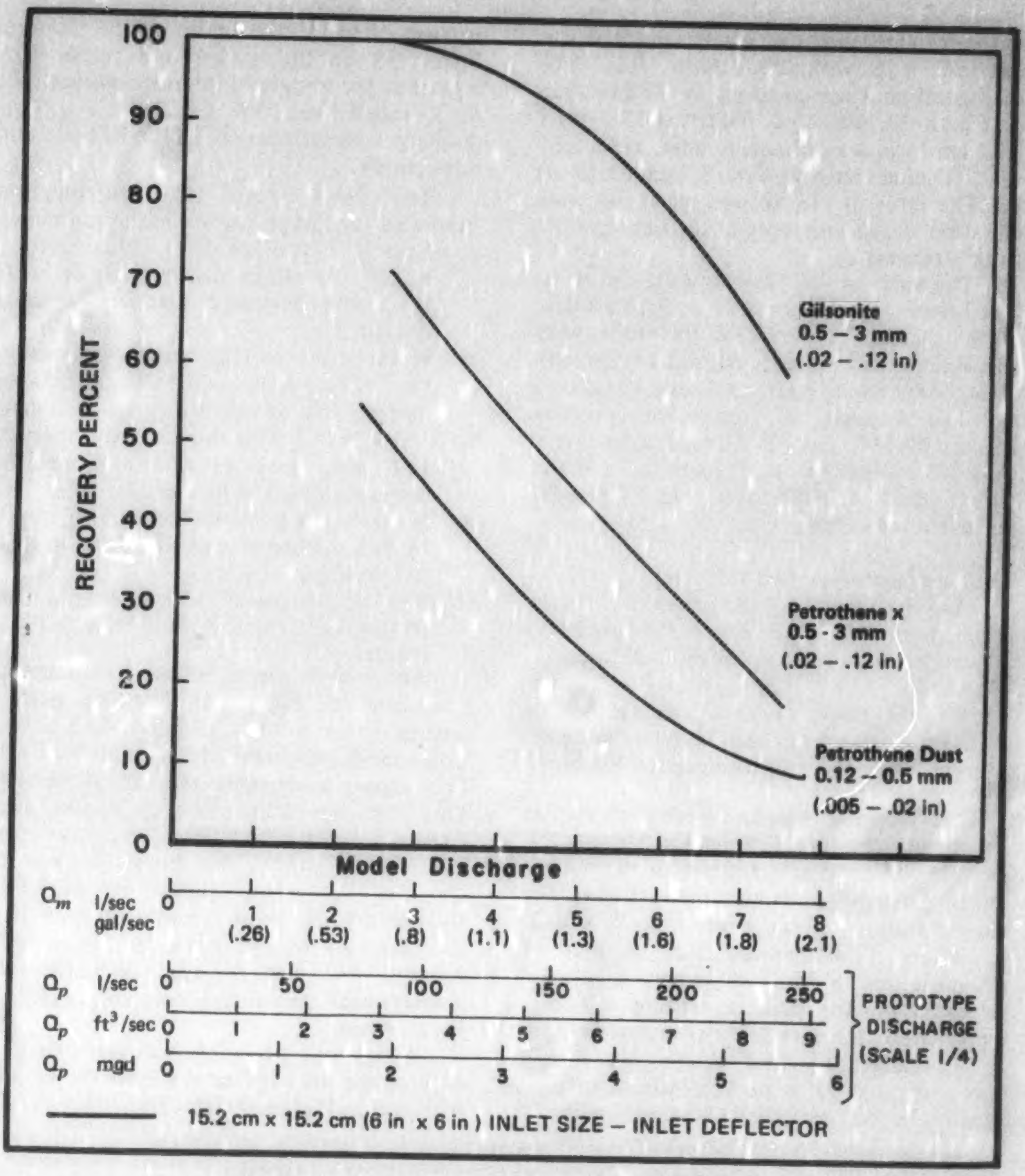


FIGURE 43 SUGGESTED RECOVERY CURVES FOR GILSONITE AND PETROTHENE IN MODEL WITH 5 PERCENT DRAW-OFF

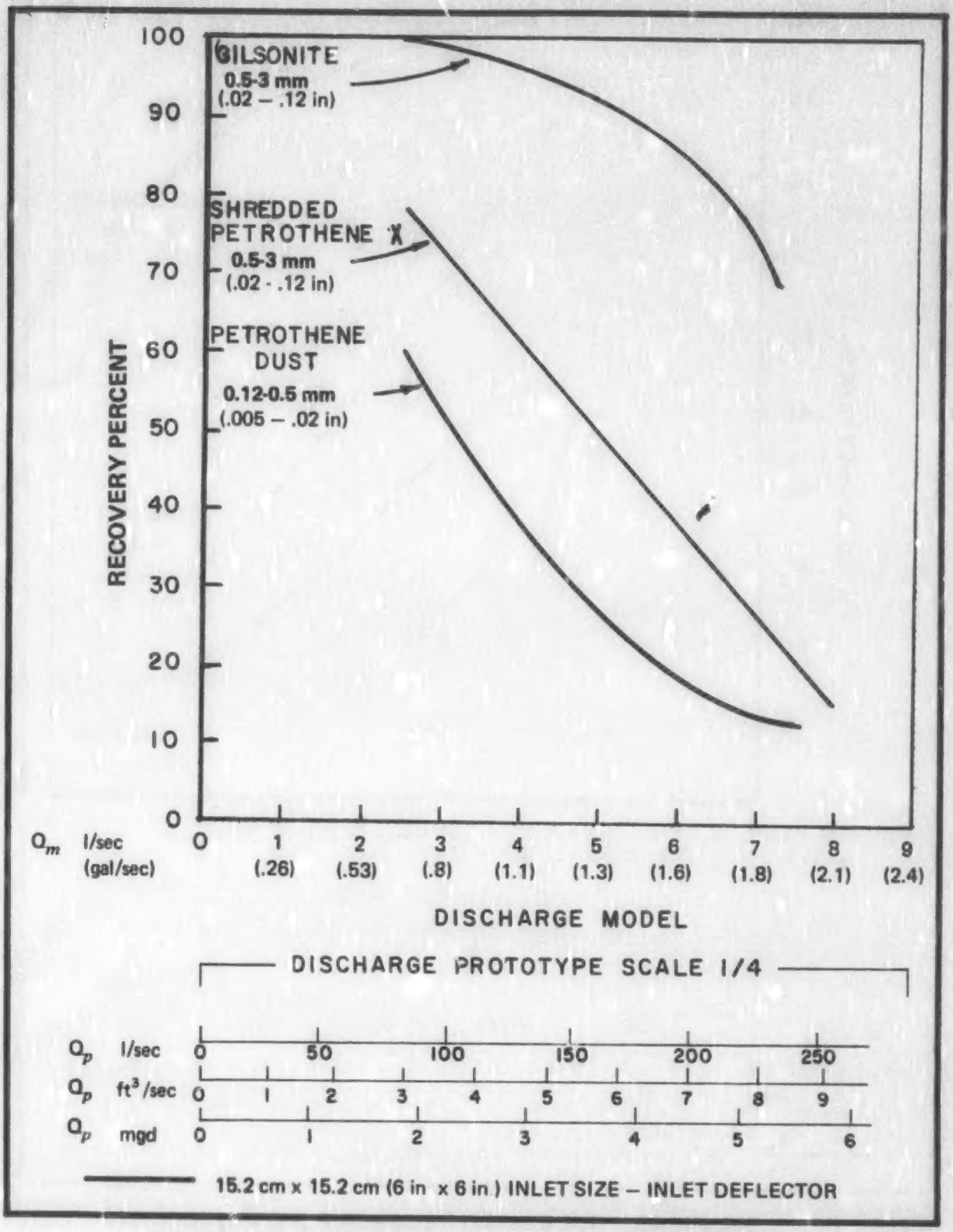


FIGURE 44 SUGGESTED RECOVERY CURVES FOR GILSONITE AND PETROTHENE IN MODEL WITH 10 PERCENT DRAW-OFF

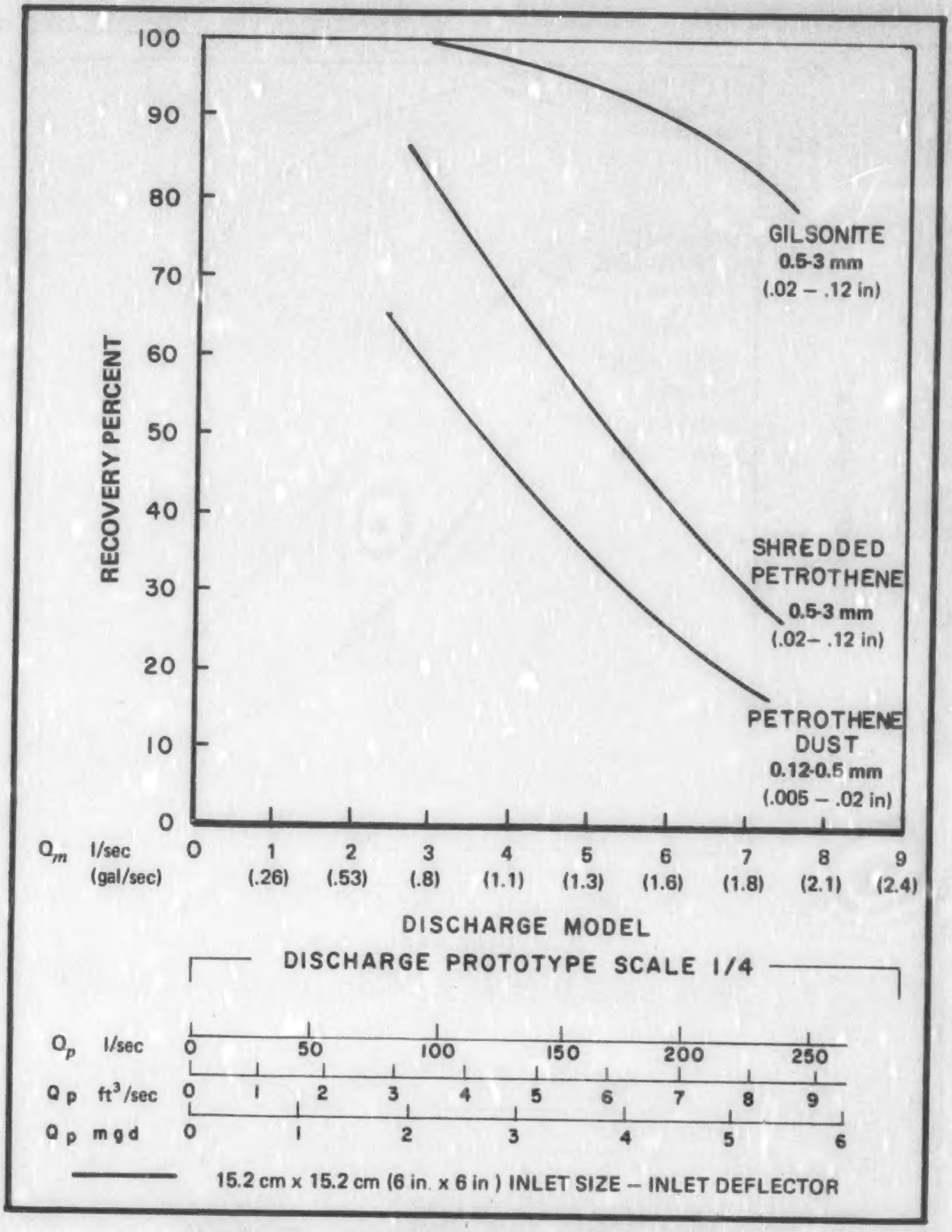


FIGURE 45 SUGGESTED RECOVERY CURVES FOR GILSONITE AND PETROTHENE IN MODEL WITH 14 PERCENT DRAW-OFF

After the range of discharge of normal operation for the prototype had been determined, computations were carried out to determine the corresponding retention time. The approach followed was to take the whole volume of the chamber up to the circular weir lip crest level and to subtract the volume of both the weir and central overflow pipe. The results of this computation are presented in Figure 46, Retention Times for Prototype.

REFERENCES

7. *Hydraulique et Granulats,* Jean Larras, Eurolles, Paris, 1972, 256 pp.

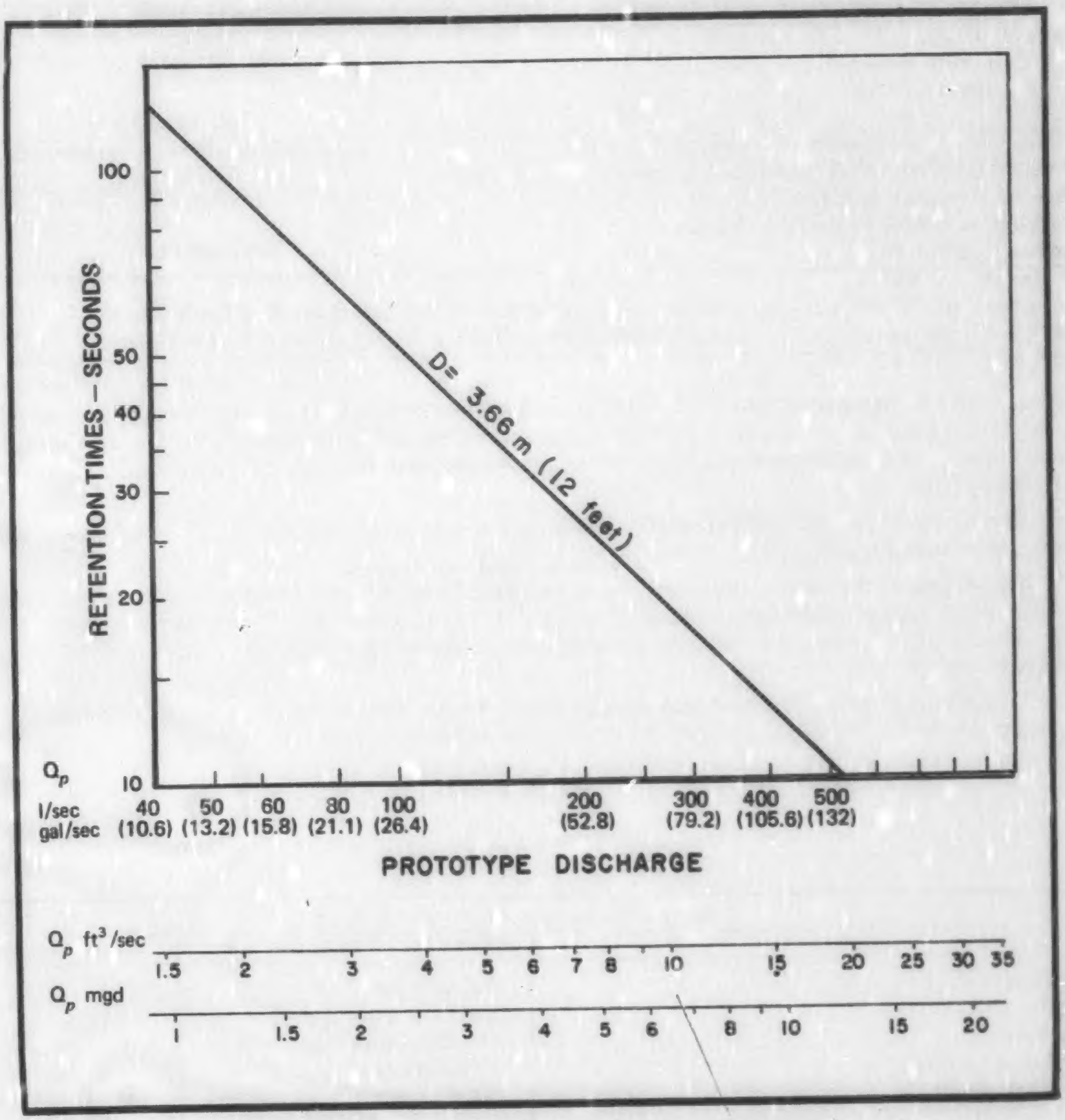


FIGURE 46 RETENTION TIMES FOR PROTOTYPE